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MANUAL OF FISHERIES SCIENCE

Part 2 - Methods of Resource Investigation and Their Application

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 1974

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MANUAL OF FISHERIES SCIENCE

Part 2 - Methods of Resource Investigation and their Application

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This document was produced in a provisional version solely for use as background documentation at the FAO/DANIDA Training Centre in the Methodology of Fisheries Science held in Frederikshavn, Denmark from 28 August to 22 September 1972. On the basis of the experience gained in using it as training material it has been revised and edited with a view to circulating it for comment by international workers in this field.

This revised version will be used at the second FAO/DANIDA Training Centre in the Methodology of Fisheries Science (Biology) to be held in Kelibia, Tunisia, from 29 July to 23 August 1974. Comments and criticisms are welcomed and should be addressed to the Aquatic Resources Survey and Evaluation Service, Fishery Resources and Environment Division, FAO, Rome.

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FAO manuals, fisheries science - methodology. Population and sampling - statistical terms, stratified sampling, market sampling, sampling on vessels, catch statistics and effort data. Measurement of fish and shellfish - biostatistics, standard norms, recording, grouping and conversion of data. Age determination and age composition - otoliths, scales, ageing methods, growth rate, age-length relationships. Sex, maturity and fecundity - determination, stages, maturity, indices, relationships. Food and feeding - ecology, biological production, food intake, stomach content study. Aquatic environment - physical, chemical and aquatic characteristics, productivity, surveys. Fish stock study - unit stocks, migrations, stock differentiation - marking, tagging, methods and techniques - parasite studies, immunogenetic studies, meristic characters. Fishing effects on fish - abundance estimates, absolute and relative methods - mesh and gear selectivity. Population dynamics - mathematical models, monitoring of stocks. International coordination and cooperation. Appendixes with various examples. Selected bibliography.

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1. INTRODUCTION TO FISHERIES SCIENCE

1.1 History of Fisheries Science

To date the history of man's exploitation of fish resources makes dismal reading. Almost the first records which exist about fisheries are those concerning the decline in the yield from one fishery or another. The record continues today. However, it was not until the 19th century that a combination of factors led to the start of fisheries science. In the second half of the 19th century the North Sea plaice fisheries were in a poor state. Increasing fishing effort was not resulting in larger catches, catch-per-unit effort was falling and the average weight of plaice in the catches was declining. It was showing all the signs of what, in today's terms, is called "over-fishing". However, fisheries had collapsed in the past without it initiating research. But the same factors that were leading to over-fishing, industrialization and advanced technology, were also providing the money to pay scientists to investigate the reasons for the collapse. As a result numerous public enquiries were held, mainly in Great Britain, to collect information which would provide an answer to the question of why the North Sea plaice stocks had declined and to determine what could be done to rectify the situation. This was the birth of fisheries science.

1.2 History of a Fishery

Once the statistics of a few fisheries had been examined it was soon realized that they showed a picture common to all. (Fig. 1.1). As total fishing effort increased with time total catch rose initially, reached a maximum and then flattened out, or even sometimes to much less than had been obtained at low levels of fishing effort. At the same time, both the catch-per-unit effort and the mean weight of the individual fish in the catch declined continuously. While it is clear that the basic reason for this is quite simple - too many fish were being caught, - in any particular fishery a detailed analysis is necessary to determine how many fish (and of what size) should be caught each year to assess the future of the fishery. This analysis depends on having the right sort of information, most of which can be obtained from the fishery itself.

1.3 Why Investigate a Fishery?

On the face of it, the history of man's exploitation has been one of success with catches rising at 7% a year since 1950 but this success is more apparent than real. The increase in catches has been obtained mainly by exploiting one virgin stock after another in succession, leaving a series of depleted stocks incapable of giving their best yields. This cannot continue indefinitely, ways must be found of controlling fishing.

The normal sequence of events in an uncontrolled fishery is that the increase in the number of fishing units usually stops because the catch-per-unit effort falls to such a low level that it becomes uneconomic to build any more. Often the number decreases as the least economic vessels are withdrawn from the fishery and the more mobile vessels, such as factory trawlers and freezers, move on to fish other stocks. It is unusual for the fishery to collapse completely (Course A in Fig. 1.1) unless the fishery has had some severe biological effect on the fish, such as reducing the breeding stock to such a low level that recruitment almost ceases; one such example is the English East Anglian herring fishery. Assuming this does not happen the fishery stabilizes at the levels shown by B on each curve in Fig. 1.1. This is far from an ideal situation; the total catch is much less than the maximum obtainable and the fishing effort required to take it is high and therefore uneconomic. If the catch-per-unit effort rises sufficiently it may attract back some of the mobile vessels and the fishery then oscillates.

The obvious objective is to reverse the sequence of events and stabilize the fishery either at some point C, near but beyond the optimum, or at point D, at which the maximum total catch is being taken, or at point E at which less than the maximum total catch is being taken but it is being taken most economically. Before decisions can be made as to how any of these objectives are to be realized, the factors underlying the shape of these curves must be determined.

1.4 The Rôle of the Fisheries Scientist

Before discussing this point it is important to consider the rôle of the fisheries scientist. The majority of fisheries are international and many of them are regulated by international commissions, which either regulate all the stocks in a given area or certain species. Examples of the former are the Northeast Atlantic Fisheries Commission (NEAFC) and the International Commission for the Northwest Atlantic Fisheries (ICNAF), which between them regulate fishing in much of the North Atlantic, and an example of the latter is the Pacific Halibut Commission which regulates the fishery for that one stock of halibut. All nations which fish the stocks in a commission's area or the stock, in the case of a single species commission, should be represented upon it if it is to be effective and they usually are.

The fisheries scientists present their data to the commissions but the scientists do not make the final decisions upon regulations. These are made by administrators and politicians both of whom take account of national as well as international interest. It has been a feature of regulations within fisheries commissions that short-term national interests tend to outweigh longer terms, or international interests. This tendency is increased if the scientific advice is uncertain or inconclusive. The history of the International Whaling Commission is a classic example.

Thus the fisheries scientist not only has his responsibility to collect data so that he can advise but also the responsibility to collect his data in the best possible manner so that he can advise with confidence and precision. Because a fishery fluctuates from year to year he also needs to monitor it, up-date his assessments and continue his research into improving his methods.

1.5 How to Investigate a Fishery

Before a fisheries scientist can even start giving advice he must know what information he must collect in order to describe his fishery. A series of investigations are involved, for many of which the fishery provides the data.

1.5.1 Catch and fishing effort data

These data are provided by the fishery and are often the only data available. Records of total catches are usually available long before any other information because the information about the catch, and its value, are important for economic reasons. However, catch tells us little about the state of the fishery; as shown in Fig. 1.1 the same total catch could be taken from an underfished as well as an overfished stock. To have a real understanding of the fishery some measure of fishing effort is required. It is not always easy to collect a meaningful index of fishing effort but sometimes quite crude estimates will suffice.

1.5.2 Length and age composition data

The other data provided by the fishery are length compositions and, but not always, age data. However, catches are usually very large; for examples the number of anchoveta caught by Peruvian ships in a year may be more than 10,000,000,000. It is impossible to measure all these and a sampling system needs to be devised so that the measurements of a few fish provide reliable information about the total catch. If a good statistical system is used to sample the catches and the samples taken in accordance with a prescribed pattern then the characteristics of the population (for example, the length distribution of Peruvian anchoveta) can be estimated to any desired level of precision.

1.5.3 Biological investigations

Certain investigations have to be done by the fisheries scientist. Of these the determination of the stock structure is the most important because it is essential to link catches with the fish stock from which they are taken. This is usually determined by tagging or less usually by some other method, such as the study of meristic character.

The fish is also part of its environment and reacts to it when migrating so studies of currents are important. In up-welling areas the pattern of the current systems can have a decisive effect upon the fishery. The physical and chemical characteristics of the currents also determine to a large extent the basic productivity of a region upon which the ultimate sizes of the stocks depend. The study of phytoplankton, zooplankton and the feeding of fish are all links in this chain even though studies to date have been of little use in helping to solve fisheries problems.

1.5.4 Population dynamics

To put all this information to use methods of population dynamics are required to enable the fisheries scientist to answer the questions posed by the exploitation of a fishery, which were outlined earlier. Population dynamics depends upon building models which describe the fishery and allow prediction. Given accurate data the better the model the more correct the prediction will be.

1.6 The Scope of this Manual

This series of studies described in sections 1.5.1 to 1.5.4 are the basic building blocks of any fisheries investigation and this manual provides an introduction to the main ways in which these studies are conducted. No section is comprehensive, because each is intended to lead on to further study on each topic, but each is designed to show what methods of research are available and how this research should best be conducted to enable the fisheries scientist to meet his objectives. According to Gulland (1971) the yield from the traditional bony-fish resources is nearly at its estimated maximum level of 100,000,000 tons a year and there are few unexploited stocks to develop. For further expansion we shall then be dependent upon non-traditional resources, such as krill. In this situation we are even more obliged to exploit our traditional fisheries resources in the best manner possible. To do this the fisheries scientist must play a major rôle.

1.7 References

Gulland J.A., The fish resources of the ocean. Fishing News (Books) Ltd., London, 1971 255 p.

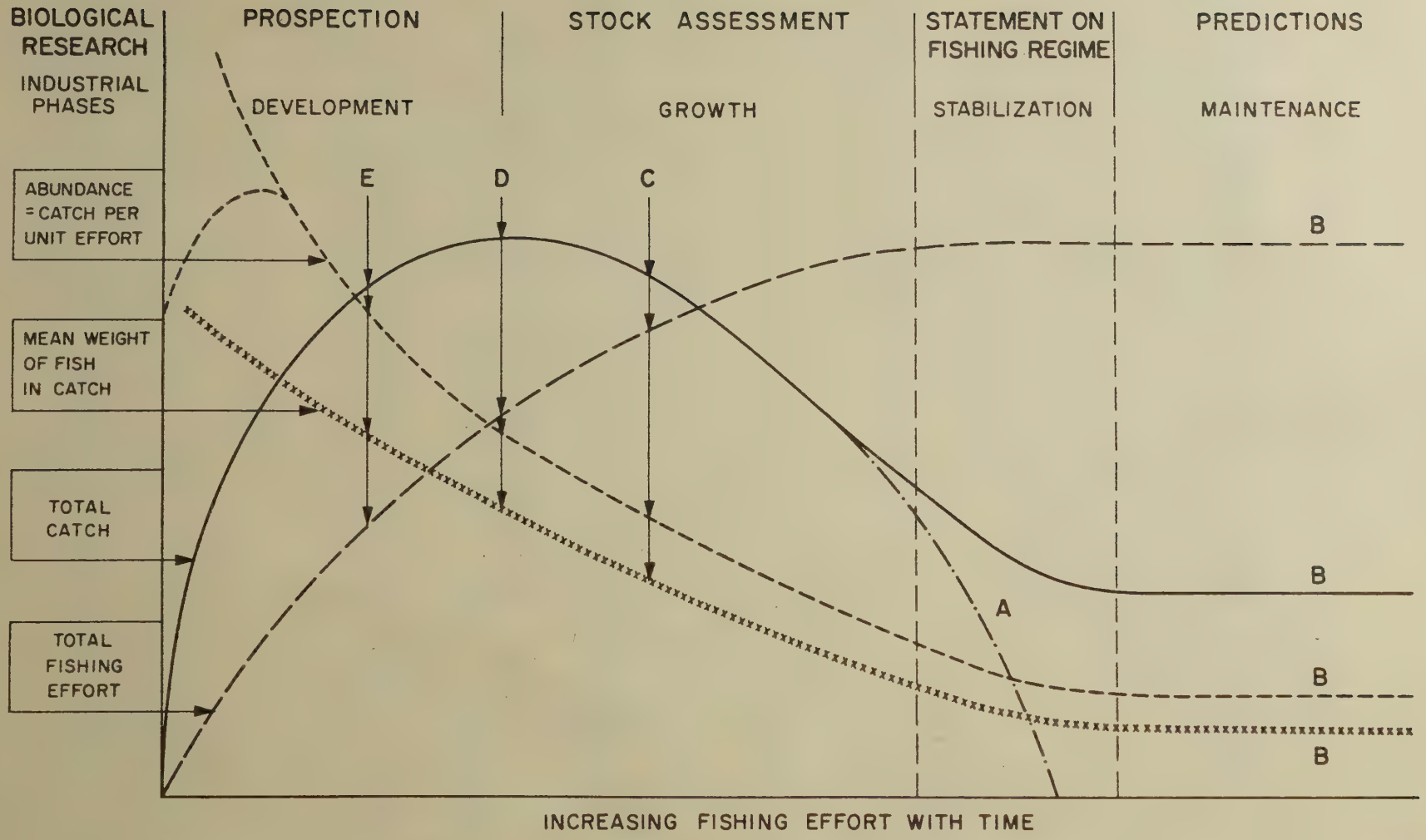


Fig. 1.1 Generalised history of a fishery

2. POPULATION AND SAMPLING

"Taking samples" is a procedure used in nearly all fisheries investigations and from the sample taken we wish to be able to generalize about the population under investigation; for example, having measured a sample of Haplochromis mloto from Lake Malawi, we want to be able to say something specific, for example about the length-range of all the H. mloto in Lake Malawi. If we are to be able to do this our sample must be taken carefully.

Firstly, we must define what we mean by a population. In the example just described it was all the H. mloto in Lake Malawi but it can be defined as all the subjects or material of like kind about which we wish to generalize from our sample. So, in one instance the population might be all the fish of one particular species landed at a particular port in a particular week; for example, all the Alestes baremose landed at Wanseko, Lake Sessesako Mobutu (Lake Albert) Uganda between 17-30 March 1974. In another instance it might be all the fish of a particular species in a small pool at a particular time. In another instance it could be all the fish caught in a single trawl haul and landed on deck.

The efficiency of any sampling scheme is related to whether it allows a satisfactory generalization to be made about the population from the sample or samples. There are two main reasons why samples may not permit us to be precise in what we say about the population. These are Random Sampling Error and Bias.

2.1 Random Sampling Error

When we take a sample it is unlikely that it will exactly represent the population from which it was drawn. For example, if we are sampling a landing of fish for length our random sample might contain a rather greater proportion of large fish than we would in fact find if we measured all of the fish in the landing. How is it caused? When we draw a simple random sample from a population we give all individuals in that population an equal chance of being chosen as members of that population but chance can and usually does cause individuals of some types to be over-represented and individuals of other types to be under-represented. This is random sampling error. Random sampling error can be reduced by taking larger samples and in certain cases can be reduced by sampling in another way (e.g. stratified sampling). Whether random sampling error prevents us making a valid generalization from our sample to the population will depend on the degree of precision we require of our generalization. For example, if we wish to obtain an estimate of the proportion of different lengths in the catch for the purpose of advising, say, a fish processing company of the approximate composition of the catch, it is quite probable that we and they might be content with answers which were less precise than we would wish to obtain if the results of the sample were to be used as the basic data in a scientific assessment of the fish stock, which would subsequently be used to set a catch quota.

2.2 Bias

Bias is caused by systematic error. For example, if the board we used was incorrectly numbered so that all lengths were recorded as being 1 cm longer than they actually were a systematic error of 1 cm would be introduced. This is an example of a bias. Less obviously, bias could occur if only fish from the tops of boxes were measured because selected large fish might have been put there by the fishermen to make buyers think that the boxes contained more large fish than they actually did. The reverse might happen if large fish were not put into the boxes because they were being kept aside by the fishermen for favoured buyers.

In both cases a biased sample would result because neither sample would allow us to generalize accurately about our population; the fish being landed. A bias is not removed by taking larger samples because it is caused by a basically incorrect method of obtaining a sample of the population. A known bias in a sampling scheme may be acceptable. For example, a trawl survey to determine the relative proportions of fish of two different species might

be biased because the fishing gear might be more efficient at catching fish of one species than fish of the other. However, the results of such a survey would be perfectly usable if we knew that one species was twice as catchable as the other. Unfortunately, the recorder often may not be aware that the results he is obtaining are biased as causes of bias are difficult to detect, as the following examples show.

An investigator picking individual fish from a pile nearly always picks out the largest fish first causing the mean length of the sample to be systematically larger than in the pile, in this case the population being sampled.

Gulland (1966) describes types of biases that met an investigator sampling fish at Lowestoft Fish Market, when he wanted to get an estimate of the mean length of the herring landed. Being in time he always came early and took his samples from the first landings in the morning. Later it was found out that the first landings came from the boats that had been fishing nearest to the coast where the fish were, on average, smaller than those from greatest depths. Thus the sample mean was systematically smaller than the population mean (mean length of all fish landed that day).

Samples of fish always taken from the same ship, because the laboratory has good relations with the crew, are likely to be biased because individual fishing skippers normally have their own preferences in fishing places and different ways of rigging and operating their gear.

Bias due to differences between individual investigators was found during the ICES Herring Tagging Programme 1957-58 (Aasen et al, 1961) who reported how three tagging teams under identical circumstances (tagging on board the same ship, on the same catch, etc.) consistently got significant different percentages of recapture of the fish tagged.

It is also well known how different persons get different results of age readings on the same otoliths. Subjectivism is very abundant in connection with the determination of maturity stage of gonads. The very important bias in the system we use for sampling the population of fish in the sea arises when fishing with gear that only select certain size groups of fish and this is discussed in section 9.

Bias can be detected only if: the whole sampling system from catching to subsequent laboratory analysis is studied in detail; if the reasons for it can be detected it may be able to rectify the data e.g. adding 1 cm to all fish lengths which have been measured on a board with an origin at 1 cm instead of zero.

2.3 Some Statistical Terms

This is not a text book of statistics many of which are available for those interested in that subject and the statistical concepts related to sampling are described in detail by Gulland (1966). However, knowledge of four statistical terms is required to understand something about sampling.

2.3.1 Mean

Let us say we took a very small sample of 16 fish, measured them and obtained the following results:

length (cm)	4	5	6	7	8	9
number of measurements	2	1	2	6	4	1

The mean is calculated by adding all the individual lengths and dividing by the number of fish:

$$(4 + 4 + 5 + 6 + 7 + 7 + 7 + 7 + 7 + 7 + 8 + 8 + 8 + 8 + 9) / 2 + 1 + 2 + 6 + 4 + 1$$

or more simply $(4 \times 2 + 5 \times 1 + 6 \times 2 + 7 \times 6 + 8 \times 4 + 9 \times 1) / 2 + 1 + 2 + 6 + 4 + 1$

which equals $8 + 5 + 12 + 42 + 9/16 = 108/16 = 6.75$ cm

which is the mean of these observations.

This set of calculations can be described in a mathematical shorthand by writing:

$$\frac{\Sigma x}{n} = \bar{x}.\Sigma$$

(pronounced 'sigma'), which simply means 'the sum of' or 'add up all the observations' and Σx means add up all the observations which we have called x; x is called the variable. If we divide this by n, the number of fish in our sample, we get $\bar{x}$ (pronounced x bar), the mean.

We could take another sample of 8 fish and get the following results:

length cm	4	5	7	7	8	9	10
number of measurements	2	1	1	1	1	1	1

$\Sigma x = 54$, $n = 8$ so $\bar{x} = 54/8 = 6.75$ cm

These two sets of observations have the same mean but they look very different. In the first set most of the fish were 7 cm and 8 cm long; in the second set only one length group (5 cm) had more than one observation in it. So the mean does not tell us a great deal about the numbers in each length group in the sample. To describe it better we have to calculate the variance and the standard deviation.

2.3.2 Variance and standard deviation

The variance is defined as the sum of the squares of the deviations of the observations from this mean divided by one less than the total number of observations and it is usually written s^2. It is written σ^2 (pronounced sigma squared) when it is the variance of a population and not of a sample. In statistical shorthand

$$s^2 = \frac{\Sigma(x - \bar{x})^2}{n - 1}$$

$(x - \bar{x})$ is the deviation of an observation from the mean, $(x - \bar{x})^2$ is the square of the deviation and Σ means 'add them all up' as it did in section 2.3.1. The standard deviation is the square root of the variance.

For the first set of observations in section 2.3.1.

$$s^2 = \frac{(4-6.75)^2 + (4-6.75)^2 + (5-6.75)^2 + \ldots + (9-6.75)^2}{16 - 1}$$

$$= 2.06$$

$$s = \pm 1.43 \text{ cm}$$

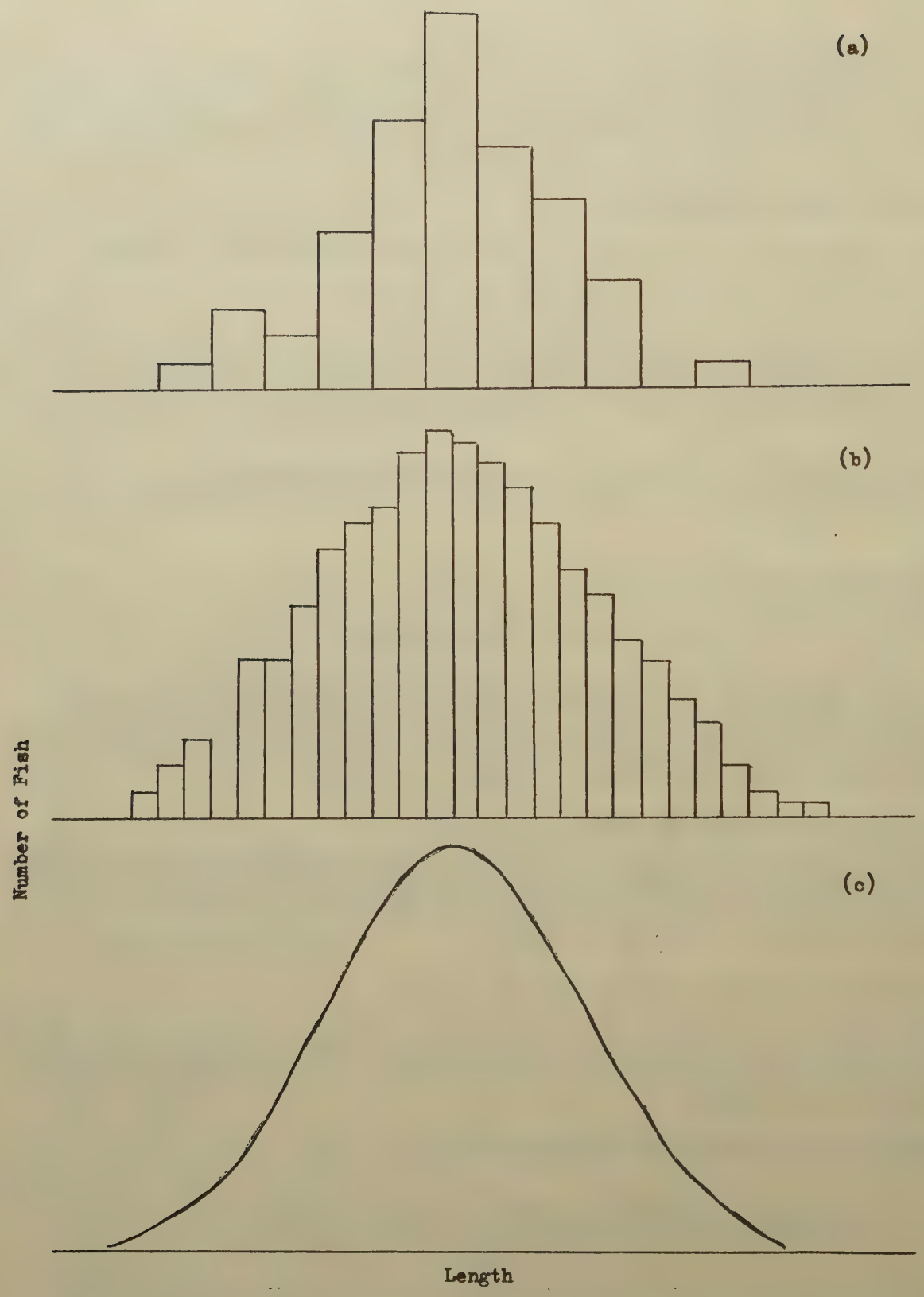


Fig. 2.1. (a) Histiogram based on few fish measured in units of 10 mm
(b) Histiogram based on many fish measured in units of 5 mm
(c) Infinite number of fish measured in infinitely small units - Normal curve

The three dots means that I did not want to put in the square of the deviations for all the observations. This is a long and tedious way of calculating the variance and it can be proved that:

$$s^2 = \frac{\Sigma(x - \bar{x})^2}{n}$$

$$s^2 = \left[\frac{\Sigma(x^2) - \frac{(\Sigma x)^2}{n}}{n - 1}\right]$$

This formula makes calculation much easier, especially on a calculating machine. It is very important to note what the brackets mean; $\Sigma(x^2)$ means add up all the values of x^2; (Σx^2) means add up all the values of x and then square the result. Taking the first sample in section 2.3.1 again

$$\Sigma(x)^2 = 4^2 + 4^2 + 5^2 + 6^2 + 6^2 + 7^2 - - - - - + 7^2 + 8^2 + 8^2 + 8^2 + 8^2 + 9^2 = 760$$

$$(\Sigma x)^2 = (4 + 4 + 5 + 6 + 6 + 7 + - - - - - + 7 + 8 + 8 + 8 + 8 + 9)^2 = (108)^2 = 11664$$

$$s^2 = \frac{760 - \frac{11664}{16}}{16-1} = 2.06$$

which is exactly the same result as we obtained by the long method of calculation.

2.3.3 Normal distribution and confidence limits

Many of the observations which fisheries scientists made, such as the number of fish in each length group in a sample or the number of fish at each age in a length group form histograms of the type shown in Fig. 2.1a. If the class intervals in such a histogram were made smaller (5 mm instead of 10 mm) and the number of fish measured increased, the outline of the histogram would become smoother (Fig. 2.1b). Continuing this process indefinitely would produce a bell-shaped curve as in Fig. 2.1c. This bell-shaped curve is called the Normal Curve. It is defined entirely by its mean and its standard deviation; the latter describes its spread (Fig. 2.2). For such a curve there is a relationship between the deviation from the mean ($\bar{x}$) expressed as a multiple of its standard deviation, in this case σ because the normal curve describes a whole population, and the frequency with which these deviations should occur. In particular 95% of the individuals should lie between $\pm 1.96\ \sigma$ of the mean. If we then measured one fish of the same species to which the curve refers and found that its mean length was greater or smaller than $\pm 1.96\ \sigma$ then we could say that we are 95% confident that it did not belong to the population described by the mean $\bar{x}$ and the standard deviation σ. If we took a sample of n fish and determined the mean of that sample ($= \bar{x}$) then we could say that it did not come from the same population as the original if its mean was greater or less than $1.96\ \sigma/\sqrt{n}$ than that of $\bar{x}$. ($\pm 1.96\ \sigma$) describe the 95% confidence limits of a normal distribution. If we wanted to be more accurate and describe the confidence limits within which we were 99% certain that the mean lay we should have to work to $\pm 3.1\ \sigma/\sqrt{n}$.

The preciseness with which we can define whether a sample can be described as coming from the population described by $\bar{x}$ and σ depends upon the square root of the observations we take. This has an important bearing on fish sampling. If we measured 10 fish the accuracy with which we could describe the mean would be $s/\sqrt{n}$, s now referring to the standard deviation of the sample of 10 fish. If we now measured 50 fish the accuracy with which we could describe the limits of the mean would decrease by the ratio of $\sqrt{10}/\sqrt{50} = 3.16/7.07 = 0.45$.

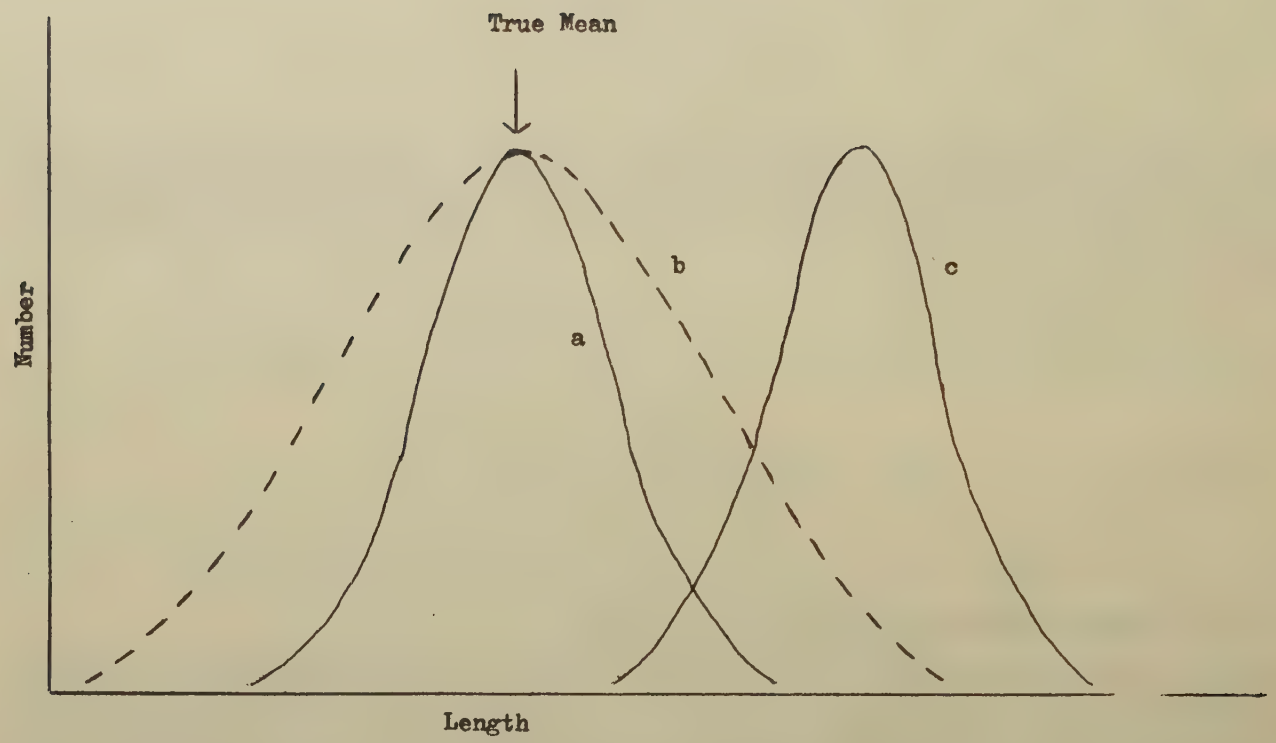


Fig. 2.2. Three normal curves: (a) with small standard deviation, (b) with large deviation and (c) with small standard deviation but positively biassed to right of true mean (i.e. mean of c should be the same as that of curves a and b)

If we measured 100 fish instead of 10 it would decrease to 0.32; for 200 fish instead of 10 it would decrease to 0.22. By doubling the number of measurements from 50 to 100 we increase the accuracy with which we can define the mean by a large amount but by measuring another 100 fish we do not increase it in proportion either to the number of fish measured or to the number of fish measured or to the amount of time this would have taken.

2.4 Stratified Sampling

When sampling a heterogeneous population (that is in this case one made up of fish of widely different lengths), the precision achieved can be increased, sometimes very greatly and the risk of bias reduced by dividing the population into relatively homogenous sections (e.g. fish of similar lengths) called strata (singular, stratum). Each stratum is then sampled independently, and the estimates of mean length for each obtained. These can then be combined to give the estimate for the whole population. The variance of this estimate will also be obtained by combining the variances of the estimates within the individual strata. As these latter will tend to be small - the strata being relatively homogeneous, so that the variance within strata is less, and possibly much less than the variance in the population as a whole - the variance of the final, combined estimate will also be small.

Fish are often landed by categories which consitutute readily available strata for sampling. Gulland (1966) describes one example of the application of stratified sampling to a haddock catch landed on Aberdeen market, Scotland. The haddock were landed in few categories, or strata, large, medium, small medium and small. A sampling scheme which made use of these strata resulted in a variance of the mean length which was one seventh of that obtained by not using the strata, 0.0285 compared with 0.197.

2.5 Practical Aspects of Market Sampling

So far we have discussed mainly the theoretical aspects of sampling. More often than not sampling programmes have to be carried out in circumstances which do not allow the theory to be put into practice in complete detail. The following sections describe some of these practical difficulties and what can be done to overcome them.

How many fish to measure? To some extent this question has been answered in section 2.3.3 in which we said that the accuracy with which we could define the confidence limits of the mean increased with the square root of the number of observations. For a fish landed unsorted we might decide that 100 fish would give us the accuracy we required. If we found that one container held only 80 fish it would be better to measure one container rather than two from the landing of one ship and deploy our effort elsewhere because doubling the amount of measuring would reduce our confidence limits to only 0.71 of that if we measured one container. However, the fish might be landed in containers holding 300 fish and to avoid bias we might find it necessary to measure all the fish even though the measurements of the last 200 fish would add little to our precision of the estimate of $\bar{x}$. A slightly quicker method would be to measure only every third fish, discarding the other two. By measuring the fish in this way we avoid bias caused by picking out the largest fish first (section 2.2).

The size of the sample will also depend upon the variance of the length range of the fish in the box. After a small amount of sampling this will be known within certain limits and the size of sample adjusted accordingly.

If the fish are landed by categories then some fish of each category must be measured; if they are not bias will be introduced. In this instance the total variance for all samples from all categories will be the least if the number of fish measured in each category (n) is proportional to the product of the total number of fish in the category (N) and the standard deviation of the mean (s), that is: $n \propto Ns$. Usually the categories of large fish contain a wider length range of fish, but fewer of them, than the categories of small fish. For ex-

ample, if the standard deviation of the mean of the category 'large' was ±5 cm and the total number of fish in the category was 1000 and the standard deviation of the mean of the category 'small' was ±2 cm and the total number of fish in the category was 8000 then the ratio of sampling of large to small would be 5000:16000 = 1:32. Of course, neither of these factors will be known for any category before it is sampled, but the likely values will be known from trial market sampling programmes.

Usually several landings are sampled on one occasion and this also affects the choice of the number of fish to measure. The variation between landings by different vessels is likely to be greater than that within categories of the same vessel, simply for the reason that they probably fished different areas whereas the length composition in one box of one category is likely to be similar to that of any other box in the same category of the one vessel. Therefore it is best to measure from as many ships as possible but it takes time to move between ships. Gulland (1966) has calculated that the best allocation of sampling time, that is, that giving the minimum variance, in terms of the number of individual samples from each

$$n = \frac{s_w}{s_b}\sqrt{\frac{t_b}{t_w}}$$

where s_w = the within ship variance
s_b = the between ship variance
t_b = time spent moving from one ship to the other
t_w = time spent examining one individual fish

As most sampling programmes require raising the weight of the sample measured to the weight of the total catch of the category, complete weight units are usually measured, either in total or on the basis of measure 1 fish, discard 1 fish (as described earlier). Thus, in practice, the unit by which the fish are measured becomes the minimum sample size.

In the majority of fisheries research programmes the amount of sampling done is rarely decided by statistical criteria but by the available manpower which is limited by the amount of money a government is prepared to spend. It therefore becomes a matter of using the available manpower to best advantage by planning the sampling programme in the manner described in this section so that observations with the least variance are obtained with the least effort. The 'best' sampling programme has yet to be worked out. The reason for this is that the fisheries scientist is primarily interested in determining the number of fish in an age group or the growth curve of a fish species and the statistics for calculating the variance of these observations has as yet not been described.

2.6 Sampling on a Vessel

Sampling on a boat presents many difficulties apart from those associated with working on an unstable platform. The catch consists of many species and it is not sorted into species or species groups and categories as it is on a market. If the vessel is commercial the scientist has to work in a way that will cause the least possible interference to the normal working of the boat and often he has a very limited time in which to obtain his samples.

2.6.1 Sampling on a research vessel

On a research vessel the scientist-in-charge usually has some control over the amount of fish he catches because he can decide how much gear he will fish or how long he will fish it. The problems of sampling increase as the size of the catch increases. The objective

should be to catch as many fish as will make one easily handled sample, Several hauls each catching a quantity of fish which can be handled easily (100–200 specimens of the species of main interest) are better than one haul of 5 tons or more. However, fishing crews do get tired constantly working gear and this also sets limits to what the scientist can do.

On a research vessel the scientist-in-charge should have control over what is done with the catch. Nothing should be done until he has given his instructions. The catch rarely consists of one species and if it is taken with a bottom trawl the fish will be mixed with benthos, stones and rubbish.

The first operation is to remove the fish from the catch and to place them in containers keeping together fish of the same species, or species groups if they cannot be easily distinguished. This operation immediately introduces a bias because it has been found that people subconsciously pick up the biggest, most attractive and least spiny fish for selection first. These will be placed in the first container to be filled and the last container will hold mainly the smallest fish of the species. It would be possible to treat each container as a stratum and apply stratified sampling techniques to the containers. For example, say there were four containers, all holding the same species. A possible approach would be as follows (see also Fig. 2.3).

1st container, large fish:	weigh the fish, measure all of them.
2nd container, medium size fish:	take the fish out one by one, placing alternate fish in each of two baskets; fishes 1, 3, 5, etc. go in one basket, fishes 2, 4, 6 etc. go in the other. The fish in both baskets are weighed, the fish in one basket measured and the measurements raised by the factor of total weight divided by weight of the fish measured.
3rd container, small fish:	take the fish out one by one, placing every third fish in each of three baskets; fishes 1, 4, 7, etc. go in the first basket, fishes 2, 5, 8 etc. in the second basket and fishes 3, 6, 9 etc. in the third basket. The fish in all baskets are weighed, the first in one basket measured and the measurements raised by the factor of total weight divided by weight of the fish measured.
4th container, very small fish:	take the fish out one by one, putting every fourth fish in each of four baskets; fishes 1, 5, 9 etc. go in the first basket, fishes 2, 6, 10 etc. in the second basket, fishes 3, 7, 11, 15 et. in the third basket and fishes 4, 8, 12, 16 etc. in the fourth basket. The fish in all the baskets are weighed, the fish in one basket measured and the measurements raised by the factor of total weight divided by weight of the fish measured.

If the catch of one species is larger than this, say 9 containers, the above procedure may be too time-consuming and it will be necessary to get a manageable sample in some other way. Divide the catch in sets of 4 as nearly as possible. With 9 containers the best split would be one set of 4, one set of 3 and one set of 2 (Fig. 2.3). Take the same number of empty containers as there are in the original set and place one quarter of the fish in the first empty container, one quarter in the second empty container, one quarter in the third empty container and one quarter in the fourth empty container. Repeat this with the second, third, and fourth full containers, tipping into the original empty containers which will now hold some fish and will eventually be full. This procedure is repeated with the set of 3 containers, putting one third of the fish into each empty container. When there are originally only two containers with fish it is better to split the dividing into two operations,

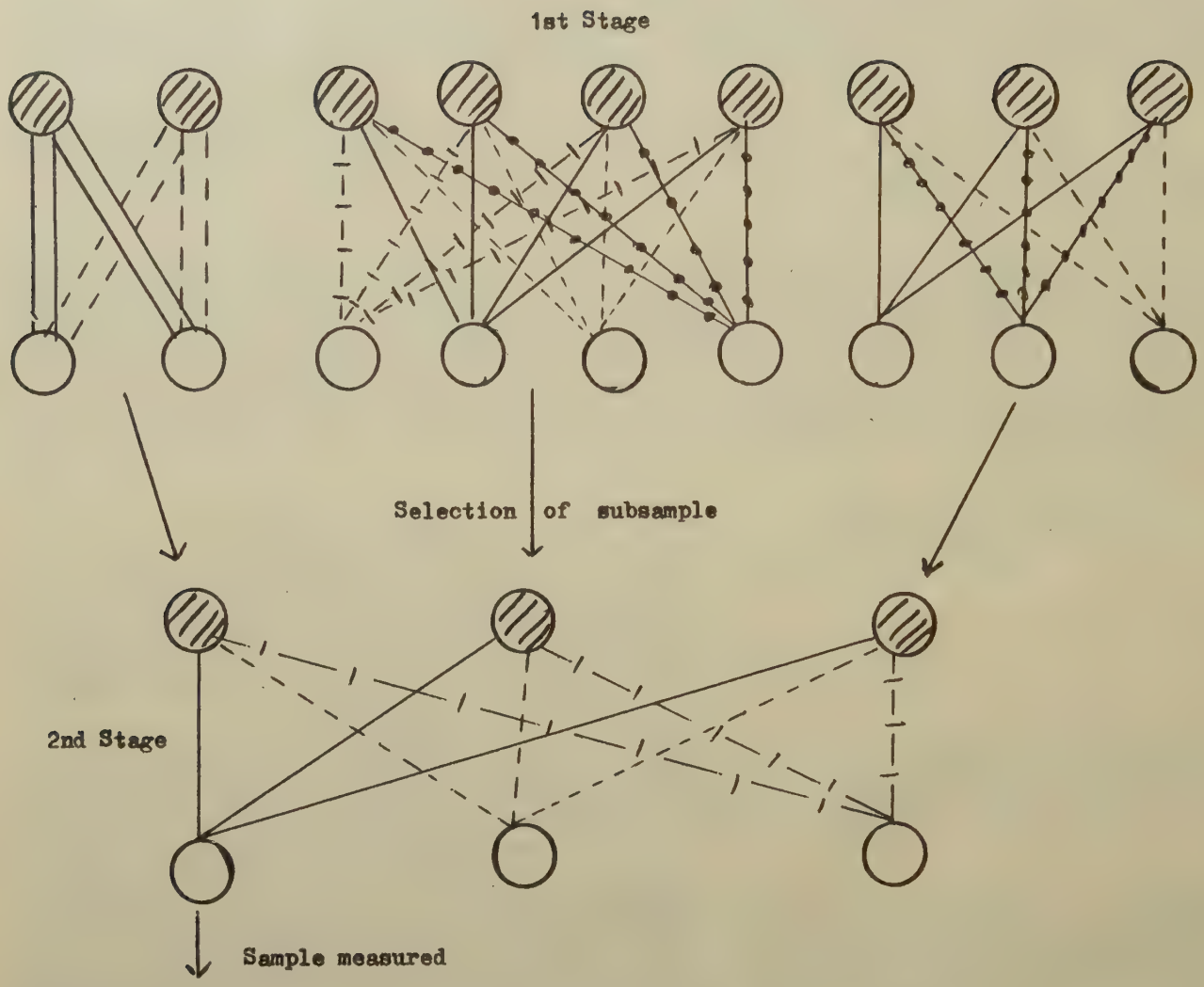


Fig. 2.3. Sub-sampling on a commercial trawler: each line in stages 1 and 2 represents division of part of the full baskets ($\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$ depending upon number of baskets at start of stage) into the empty baskets. Double line indicates that 1st and 3rd quarters are placed in one empty basket and 2nd and 3rd in the other. Full baskets at start of stage shown cross hatched.

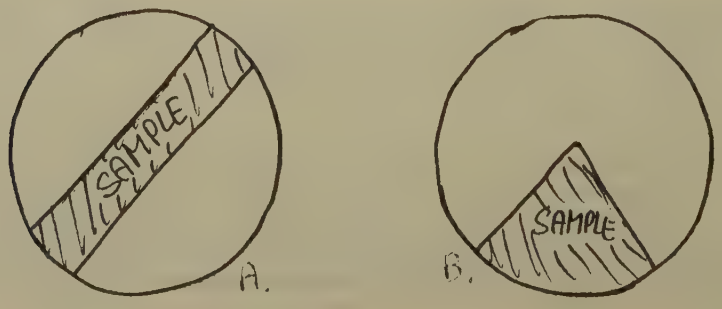


Fig. 2.4. Sampling large catches

putting the first and third quarters from the first full basket into the first empty basket and the second and fourth quarters into the second empty basket. The same should be done with the contents of the second full basket.

From each of these sets of newly-filled baskets one is selected for measuring or the procedure is repeated until a sample of the required size fish is obtained. All the fish are weighed and the length measurements of the sampled raised to the total weight of the fish caught.

Dividing the catch between containers can be done by weighing but unless the water is flat calm weighing on a boat is not accurate and the division can be done almost as accurately by tipping the fish into the containers and estimating when they are one third or one quarter full.

The purpose of this procedure is to eliminate any bias that arose when the fish were originally picked off the deck.

If the fish were sorted by species groups the sorting into species is done as the fish are measured. Division into males and females is done at the same time.

The choice of which container of fish to keep and which to throw away can be decided arbitrarily; all the baskets should contain the same mixture of fish. Alternatively it can be decided by rolling an unbiased dice after numbering the containers or using a table of random numbers (Table 2.1). If this table is used allocate any number between 00 and 99 to each container, start at any number in the table and read either horizontally or vertically until you reach one of the numbers on the container; select the fish in this container for measuring. If more than 100 containers have to be sampled, say 200, the figures in the left hand column can be used to allocate the pairs of random numbers, taking 1, 3, 5 etc. to 0-99 and 2, 4, 6 etc. to refer to 100-199. For over 200 baskets 1, 4, 7 etc. would refer to 0-99, 2, 5, 8 etc. to 100-199 and 3, 6, 9 to 200-299 etc.

See Table 2.1 on next page.

2.6.2 Sampling on a commercial vessel

The scientist on a commercial vessel will have to fit in his sampling with the work of the crew unless the commercial vessel is chartered, when the scientist-in-charge should have the same control as if he were on his own research vessel.

The catch may be very large and so he should aim to sample it in a manner which will give the least bias. Two methods of taking a sample from a pile of fish are shown in Fig. 2.4. This figure represents the view, looking down from above, on a catch from a trawl haul. It may be possible to take a large sample originally but not to measure it all because the crew want the fish for gutting. The large sample will need to be subsampled, say by mixing with a shovel and keeping one basketful obtained by placing every second, third or fourth shovelfull (depending upon the size of the original sample) into the basket of fish to be measured. The type of sampling shown in Fig. 2.4 may have to be adopted on a research vessel when very large amounts of fish are caught.

Another way of working on large commercial vessels where the fish are gutted and washed is to measure fish as they leave the washer. The scientist must first estimate by looking at the size of the catch what proportion he wishes to measure; say it is a twentieth, he then takes every twentieth fish as it leaves the washer. This is particularly easy if only one species is being measured.

The important facts to remember when working on a commercial vessel are first, do not upset the crew and second, adapt your technique of sampling to fit in with the working of the ship so as to obtain the least bias possible. If you cannot avoid bias record what you think is the bias.

Table 2.1. Table of Random Numbers

	First Thousand									
	1–4	5–8	9–12	13–16	17–20	21–24	25–28	29–32	33–36	37–40
1	23 15	75 48	59 01	83 72	59 93	76 24	97 08	86 95	23 03	67 44
2	05 54	55 50	43 10	53 74	35 08	90 61	18 37	44 10	96 22	13 43
3	14 87	16 03	50 32	40 43	62 23	50 05	10 03	22 11	54 38	08 34
4	38 97	67 49	51 94	05 17	58 53	78 80	59 01	94 32	42 87	16 95
5	97 31	26 17	18 99	75 53	08 70	94 25	12 58	41 54	88 21	05 13
6	11 74	26 93	81 44	33 93	08 72	32 79	73 31	18 22	64 70	68 50
7	43 36	12 88	59 11	01 64	56 23	93 00	90 04	99 43	64 07	40 36
8	93 80	62 04	78 38	26 80	44 91	55 75	11 89	32 58	47 55	25 71
9	49 54	01 31	81 08	42 98	41 87	69 53	82 96	61 77	73 80	95 27
10	36 76	87 26	33 37	94 82	15 69	41 95	96 86	70 45	27 48	38 80
11	07 09	25 23	92 24	62 71	26 07	06 55	84 53	44 67	33 84	53 20
12	43 31	00 10	81 44	86 38	03 07	52 55	51 61	48 89	74 29	46 47
13	61 57	00 63	60 06	17 36	37 75	63 14	89 51	23 35	01 74	59 93
14	31 35	28 37	99 10	77 91	89 41	31 57	97 64	48 62	58 48	69 19
15	57 04	88 65	26 27	79 59	36 82	90 52	95 65	46 35	06 53	22 54
16	09 24	34 42	00 68	72 10	71 37	30 72	97 57	56 09	29 82	76 50
17	97 95	63 50	18 40	89 48	83 29	52 23	08 25	21 22	53 26	15 87
18	93 73	25 95	70 43	78 19	88 85	56 67	16 68	26 95	99 64	45 69
19	72 62	11 12	25 00	92 26	82 64	35 66	65 94	34 71	68 75	18 67
20	61 02	07 44	18 45	37 12	07 94	95 91	73 78	66 99	53 61	93 78
21	97 83	98 54	74 33	05 59	17 18	45 47	35 41	44 22	03 42	30 00
22	89 16	09 71	92 22	23 29	06 37	35 05	54 54	89 88	43 81	63 61
23	25 96	68 82	20 62	87 17	96 65	02 82	35 28	62 84	91 95	48 83
24	81 44	33 17	19 05	04 95	48 06	74 69	00 75	67 65	01 71	65 45
25	11 32	25 49	31 42	36 23	43 86	08 62	49 76	67 42	24 52	32 45

This table is reproduced from Tracts for Computers by Professor E.S. Pearson, No. XXIV, Department of Statistics, University College, University of London

2.7 The Collection of Fishery Statistics

All fisheries' scientists need to take samples of the fish which they study. But the fisheries' scientist who is concerned with the effect of fishing upon fish, with conservation and with advising his government on fisheries' policy must collect his data in such a way that he can build from them a model from which he can predict what will happen within the fishery he is studying. The data he collects must describe as accurately as possible the fish population from which it was collected. To do this he must collect it in a precise way. This section is concerned with the collection of catch and fishing effort statistics.

2.8 Basic Attitudes to the Collection of Fisheries' Statistics

Fishery statistics are usually required by people other than the scientists, for example, by economists. Therefore fisheries' statistics which meet the needs of everyone must be collected. However, the needs of the fisheries' scientists are usually greater than those of anyone else and a system set up by an economist is unlikely to satisfy the scientists' requirements. Therefore, the scientist must be responsible for the way in which the statistics are collected and over the staff who collect them.

Usually the staff who collect fisheries' statistics are the most junior members of the fisheries' organization, often working in isolated places under poor conditions. Yet the work that the highly-qualified fisheries' biologist does and the advice he gives depends upon the way in which these junior staff do their work. If they do it badly no amount of sophisticated analysis with computers will produce the correct results. If the original data are biased the answers derived from them will be wrong. Staff who collect statistics should be carefully recruited, properly trained and kept under close supervision to ensure they do their work properly. They will do their work better if they are made to feel part of the organization for which they work, see the fisheries' scientists regularly and, most important of all, are told how the information which they collect is being used.

Yet, in many countries the collection of fishery statistics is not always the responsibility of the fishery biologist. Often the system designed to collect fishery statistics is set up initially by the economists and it is not unusual to find a fishery laboratory, together with highly-qualified staff, attempting to work with the most inadequate basic data.

It must be remembered that the final results of any stock assessment study are directly related to the quality of the original, basic data.

2.9 Fish Identification

It may seem a statement of the obvious to say that the fisheries' scientist must know the species on which he is working but this is not always as easy as it sounds. In some areas species may be very difficult to separate and the scientist may be unaware that he is calling two separate species by the same name. If there is any doubt whatsoever it is advisable to preserve reference specimens and to consult a systematist as soon as possible during your investigation.

The individual species should be represented by special statistical categories for which separate statistics are collected. Many of the statistical categories presently in use in fishery statistics are not representative of individual species, but of species, of genera or even groups of families. In some cases species may be grouped because the catches of individuals are small; this practice should be avoided as much as possible because information is lost which may become useful if one of the species in the group later becomes important. In other cases species may be grouped because they cannot be easily distinguished in the catches.

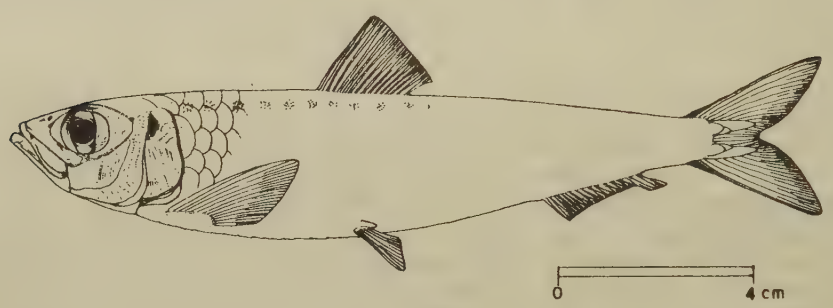
GENERAL FISHERIES COUNCIL FOR THE
MEDITERRANEAN

ORDER : Clupeiformes
FAMILY: Clupeidae

FAO Sheet No.14(En)
GFCM No.14(En)
1971

SCIENTIFIC NAME: *Sardina pilchardus* (Walbaum, 1792)

SYNONYMS STILL IN USE: *Clupea pilchardus* Walbaum, 1792
Sardina pilchardus sardina (Walbaum, 1792)



VERNACULAR NAMES:

FAO - En : Pilchard
Fr : Pilchard
Sp : Sardina

NATIONAL - ALBN:	Sardelë	ISRL:	Sardin zefoni	ROUM:	Sardea
ALGR:	Sardin'	ITAL:	Sardina	SPAN:	Sardina
BULG:	Sardina	LEBN:	Sardine mabroum	SYRI:	Sardîn
CYPR:	Sardella	LIBY:	Särdin mabrum	TUNS:	Sardina
EGYP:	Sardina	MALT:	Sardina kahla	TURK:	Sardalya
FRAN:	Sardine	MONC:	Sardina	USSR:	Sardina
GREC:	Sardélla	MORC:	Sardina	YUGO:	Srdjela

DISTINCTIVE CHARACTERS AND DIAGNOSIS:

Body rather rounded, oval in cross section; *belly not sharply keeled in the mid-line, but a shallow ridge runs from the throat to the vent; dorsal fin originates in front of the level of the pelvic fin base; gill cover strongly marked with pronounced radiating ridges; upper jaw not notched in the mid-line;* lower jaw ends in front of the hind margin of the eye; colour of the back greenish, occasionally olive, sides golden, shading to silvery-white ventrally; *a row of faint dark spots along the sides.*

Other field characters: silvery, large, fragile scales which do not extend to the head; no lateral line visible on the sides of the body; the last two rays of the anal fin are longer and broader than the preceding rays; an elongate modified scale is present on both lobes of the caudal fin.

DISTINCTION FROM MOST SIMILAR SPECIES OCCURRING IN THE AREA:

Sardinella aurita and *S. maderensis:* differ from *S. pilchardus* by the absence of radiating ridges on the gill cover and of dark spots along the sides of the body.

Fig. 2.5(a) Example of FAO Species Identification Sheet

Sprattus sprattus; differs from *S. pilchardus* by the sharply keeled belly, with a distinct line of spiny scales running from the throat to the vent, the absence of elongate modified scales on each caudal fin lobe, the position of the dorsal fin, which originates slightly behind the level of the pelvic fin origin and the absence of enlarged rays in the anal fin.

S. sprattus

Alosa alosa and *Alosa fallax nilotica:* differ from *S. pilchardus* by the presence of a distinct notch in the mid-line of the upper jaw and by the absence of enlarged rays in the anal fin.

Engraulis encrasicolus: differs from *S. pilchardus* by the prominent snout and the long upper jaw, the mouth extending well past the eye.

E. encrasicolus

SIZE:

Maximum: 22 cm in the Mediterranean, 17 cm in the Black Sea and 25 cm in the Atlantic; common: 10 to 15 cm in the Mediterranean, 6 to 8 cm in the Black Sea.

GEOGRAPHICAL DISTRIBUTION AND BEHAVIOUR:

Common in the western Mediterranean, and in the Adriatic Sea; rare in the eastern Mediterranean, the Sea of Marmara and the Black Sea; also occurs in the Eastern Atlantic from Cape Blanc to the Dogger Bank in the North Sea.

A pelagic and migratory fish, forming shoals at shallow depths (15 to 35 m at night and 25 to 55 m by day) in coastal waters over the continental shelf.

Feeds on small phyto-and zooplankton organisms.

PRESENT FISHING GROUNDS:

Coastal waters over the continental shelf.

CATCHES, MAIN FISHING GEAR AND PRINCIPAL FORMS OF UTILIZATION:

Separate statistics for this species are collected in Algeria (1970: 17 000 tons), Egypt, France (1970: 23 000 tons), Greece, Italy (1970: 44 000 tons), Malta, Morocco, Spain (1970: 32 000 tons), Tunisia, Turkey and Yugoslavia (1970: 11 000 tons), the catches recorded for 1970 in the GFCM area by these countries totalling 157 000 tons. However, unidentified quantities of *S. pilchardus* may be included in larger statistical categories by other countries.

Caught with purse seines and lamparas (light fishing), gill-nets, beach seines, trap nets and occasionally high opening bottom trawls (French Mediterranean coast).

Canning in oil or sometimes in tomato sauce is the commercially most important form of utilization in the Mediterranean; also, a rather important part of the landings is pickle-salted, or marketed fresh.

FAO species code: 1,21(05),064,01
FAO fishing area code: 37/1-8

Fig. 2.5(b)

As part of its Regular Programme activities FAO is preparing a series of Species' Identification Sheets for Statistical Purposes. It is intended ultimately to prepare one sheet for each commercially-important species recorded within each of the major fishing areas recognized on the FAO World Chart "Major Fishing Areas for Statistical Purposes". It is hoped that the Species' Identification Sheet series will help to improve the present situation by placing in the hands of the non-specialized fishery worker a practical tool for the identification of the most common commercial species occurring in his area.

An example of one such sheet for the Mediterranean area is shown in Fig. 2.5.

Fig. 2.5a and Fig. 2.5b onnext two pages.

FAO is also producing a standard classification of aquatic animals and plants for statistical purposes (FAO, 1972).

2.10 Collecting catch and fishing effort data

Collecting catch and fishing effort data is not easy. Even when the law makes it obligatory for a fisherman to give information he will not necessarily give you the correct information if he knows you have no way of checking whether he is telling you the truth or a lie. Usually you have no way of checking so you depend on him. So it is worthwhile making him your friend. Tell him why you want the information. Listen interestedly to his answers and be prepared to listen to his troubles as well. If there are laws governing the fishery, for example, minimum mesh size regulations or minimal legal landing size, try to make sure that you are not the person who has to enforce the laws. It is difficult to be friendly one day and a policeman the next. "You must have a sense of humour in everything you do. Say what you have to say with a smile", (Bazigos, 1973).

2.10.1 The collection of catch data

The first thing we wish to know is the weight of each species being landed. This, and the value of the catch, are the two quantities in which the fisheries' economists are also interested. It is impossible to give any rules about how this information is collected because they will depend upon how the catch is landed. In the large ports in England the collector of statistics can obtain the information by arranging for the trawler' owner to provide him with a sales sheet which lists weights and values by species. In some other ports the collector of statistics has to count the standard size boxes in which the fish are landed on the market and record the prices bid at auction. At the other extreme are fisheries such as those found on African lakes, where the collector of statistics has to visit each canoe as it lands and weigh the catch himself. In some instances the landing place may be so isolated that the catch must be recorded at some central point. Appendix 2.1 describes three types of fisheries and the method of recording catches for each.

There are standardized ways of recording catch and FAO has provided standard definitions of the basic terms used. These are given in Table 2.2 which is taken from FAO Fisheries Circular No. 248 "Nominal catches and landings : definitions and notes" (FAO, 1973a).

FAO Fisheries Circular No. 428 also describes standard methods of recording data where problems arise, for example, fish being transferred from the ship of the catches nation to that of the buyer nation in a third nation's port. It also includes a list of standard statistical classification of aquatic animals and plants.

2.10.2 The collection of fishing effort data

As described in section 1 it is essential to know how much fishing effort has been used to catch the quantity of fish landed because it enables an index of abundance to be calculated. Without knowing effort it is impossible to say whether an increase in landings from

Table 2.2. Table of basic definitions of 'catch' and 'landings' (taken from FAO, 1973a)

Concepts	Definitions	Synonyms	Weight Basis
Landings	The weight of fish and fish products brought ashore, i.e., the actual weight of the quantities landed. This weight represents the net weight of the gutted, eviscerated, filleted, frozen, cured, canned fish and fish products fish meals, oils, etc. at the time of landing	Landings, landed weight	Landed weight
Nominal catch	The live weight equivalent of the landings	Landings, round fresh Landings, whole fresh Landings, ex-water weight	Live weight
Catch	The term "catch", unless otherwise specified, normally refers to the "nominal catch", i.e., the live weight equivalent of the landings	Landings, round fresh Landings, whole fresh Landings, ex-water weight	Live weight
Gross catch	The weight of the fish	Real catch	Live weight
Discarded catch	That part of the gross catch which, as whole fish, is returned to the sea at the time of capture	Discards	Live weight
Retained catch	That part of the gross which, as whole fish, is not discarded	...	Live weight

The difference between "retained catch" and "landings" is due to:

(a) consumption by the crew
(b) use for bait
(c) dumping of whole fish because of spoilage or for other reasons
(d) dumping of guts, heads and other parts of the fish because of processing
(e) loss or gain of fluid content.

The difference between "retained catch" and "nominal catch" is accounted for by items (a), (b) and (c) above.

The difference between "nominal catch" and "landings" is accounted for by items (d) and (e) above.

The term "landings" is not used in international statistics synonymously with "number of arrivals" or "trips".

Data on "gross catch", "discarded catch" and "retained catch" will generally be available only in logbook entries reflecting estimates by skippers or other crew members of the quantities involved; these estimates might vary from the results ("nominal catch") obtained by converting recorded landings to their live weight equivalent.

20,000 to 40,000 tons from one year to the next resulted from the fish beingtwice as abundant and the fishing effort remaining constant, or the fish abundance remaining constant and the fishing effort doubling. Equally possible is that the fish abundance went down to a half of the first year's level and the fishing effort rose by four times.

Fishing effort data is usually collected at the same time as catch data, that is, it is collected at the point of landing for those vessels which land fresh fish or by some form of logbook system for vessels which land frozen fish infrequently, a lobgbook may be the only method. Three examples of the collection of fishing effort data are given in Appendix 2.1.

There are many ways in which fishing effort data can be recorded. FAO has issued a list of international classifications and definitions used in fishing fleet, fishing gear and fishing effort statistics and the notes on fishing effort statistics are shown in Appendix 2.2.

The important point to remember in recording fishing effort statistics is to choose an index of measure of effort which is related as nearly as possible to the abundance of the stock. For a trawler, the number of hours with the trawl fishing in the water is better than the days on ground because the trawler will not be fishing some of the days it is on the fishing ground because of bad weather. 'Days on ground' is, in turn, better than 'days absent from port' because the latter does not take in account the number of days which a trawler has to steam to and from the fishing grounds. On the other hand, for a purse-seiner, which may search for several days using sonar before locating a fish shoal, which it may then catch in a few hours fishing, 'days on ground' is a much better index of fishing effort because the abundance of the fish is related to the searching time. The actual time spent catching a shoal once it is located is not related to the abundance of shoals.

It is difficult to make sure fishing effort data are comparable over long periods. Fishing units usually get more efficient each year. In Great Britain both the tonnage and engine power of trawlers has increased. Engine power has increased at about the same rate as tonnage, so the two are comparable, and 'ton-hours' (that is, gross tonnage x hours fished) is a useful index of fishing effort which takes into account this increase in efficiency. On the other hand the engine power of Dutch beam trawlers has increased at a much greater rate than their tonnage. The increased engine power is used to drag a heavier beam trawl over the ground more quickly. In this instance the increase in efficiency is related to the engine power and not tonnage.

In gill net fisheries the change from one material to another will affect efficiency and therefore effective fishing effort; knotless monofilament nylon gill nets are more efficient than knotted, multifilament nets which are more efficient than cotton nets.

These changes are obvious and to agreater or lesser extent quantifiable by experiment. Some factors affecting fishing effort are not. The use of sonar makes a purse-seiner more efficient at searching but the degree of increase depends upon the skill of the fishing skipper. An echo-sounder in a boat may make that boat more efficient if the echo-sounder is switched on and used efficiently. But it may make it more efficient only when fish are scarce; when fish are plentiful the use of the echo-sounder may make no difference at all. Changing the hanging ratio of gill nets may make themmore efficient. These examples are used to illustrate the difficulties of collecting meaningful fishing effort data. It is a problem which fisheries' experts are still trying to solve but if the basic rules described in this section are followed the information collected will be meaningful.

2.10.3 The area of fishing

It is essential to know where the catch of a species was taken. For example, cod are landed in Great Britain from every fishing area of the North Atlantic but the catches are taken from different stocks, or populations, which do not mix. The only way in which we

CODE TO INDICATE SIZE OF RECTANGLE

Code	Latitude		Longitude
1	10'	x	10'
2	20'	x	20'
3	30'	x	30'
4	30'	x	1^{o}
5	1^{o}	x	1^{o}
6	5^{o}	x	5^{o}
7	10^{o}	x	10^{o}
8	20^{o}	x	20^{o}
9	30^{o}	x	30^{o}

CODE TO INDICATE QUADRANT

Code	Quadrant of Globe	
1	NE	Northeast
2	SE	Southeast
3	SW	Southwest
4	NW	Northwest

Size Quadrant

x x

xx^{o} xx' xxx^{o} xx'

Latitude Longitude

Fig. 2.6 A graticule system (based on latitudes and longitudes) for identifying statistical rectangles (from FAO 1973b)

Table 2.3 Major fishing areas for statistical purposes (from FAO, 1973b)

	INLAND WATERS
01	Africa
02	America, North and Central
03	America, South
04	Asia
05	Europe
06	Oceania
07	USSR
(08)	(Antarctica)

	MARINE AREAS
	Atlantic Ocean and adjacent seas
18	Arctic Sea
21	Atlantic, Northwest
27	Atlantic, Northeast
31	Atlantic, Western Central
34	Atlantic, Eastern Central
37	Mediterranean and Black Sea
41	Atlantic, Southwest
47	Atlantic, Southeast
48	Atlantic, Antarctic
	Indian Ocean and adjacent seas
51	Indian Ocean, Western
57	Indian Ocean, Eastern
58	Indian Ocean, Antarctic
	Pacific Ocean and adjacent seas
61	Pacific, Northwest
67	Pacific, Northeast
71	Pacific, Western Central
77	Pacific, Eastern Central
81	Pacific, Southwest
87	Pacific, Southeast
88	Pacific, Antarctic

can relate the effect of fishing to what is happening in each stock is to record the area from which the catch was taken. This may present few problems if the vessel has been fishing in one area only. But large freezer trawlers may be at sea for three months or more during which they may have fished several different areas of the world. In this case it is usually only possible to get an estimate from the fishing skipper of the quantity of fish taken in any area. As for the recording of catch, the method of recording fishing area will depend upon the nature of the fishery.

Appendix 2.1 describes three examples.

It is important to record fishing area in a standard way and FAO has proposed a set of major areas for statistical purposes (Table 2.3) and a set of statistical rectangles for this purpose (Fig. 2.6).

Fig. 2.6 see the following pages.

Table 2.3 see the following pages.

FAO's system allows for the recording of catches by very small statistical squares (10' latitude x 10' longitude). If data can be recorded in this manner the fishery can be examined in detail but usually it is possible to get meaningful information for much larger areas only. It is important to make whatever statistical divisions that are used correspond to the realities of the fishery. Fishermen will give information by the names they give to their fishing areas. It is much easier to record this information if the statistical squares correspond as closely as possible to the fishermen's areas. Also each area should correspond to the distribution, or partial distribution, of one stock of fish.

2.10.4 Date of capture

We want to know when the fish were captured, usually within a week or within a month. Little difficulty is usually found in collecting data of capture with this precision except for vessels which have been at sea for long periods when it may be necessary to assume that the catch was all caught in a certain month or to divide it arbitrarily between the months the vessel has been at sea, unless there is logbook information available. This information is used for analyzing seasonal abundance, migrations and in some cases obtaining growth data.

2.10.5 The importance of recording data in a standard method

Throughout this section stress has been placed upon recording information in a standard manner. The reason for this is that the majority of marine fisheries and many freshwater fisheries are international. Several nations may be taking fish from a stock and recording information. While much can be learnt from national data, stock assessments require international data and the problem of combining data from several sources is made very much more difficult if they are not in the same form.

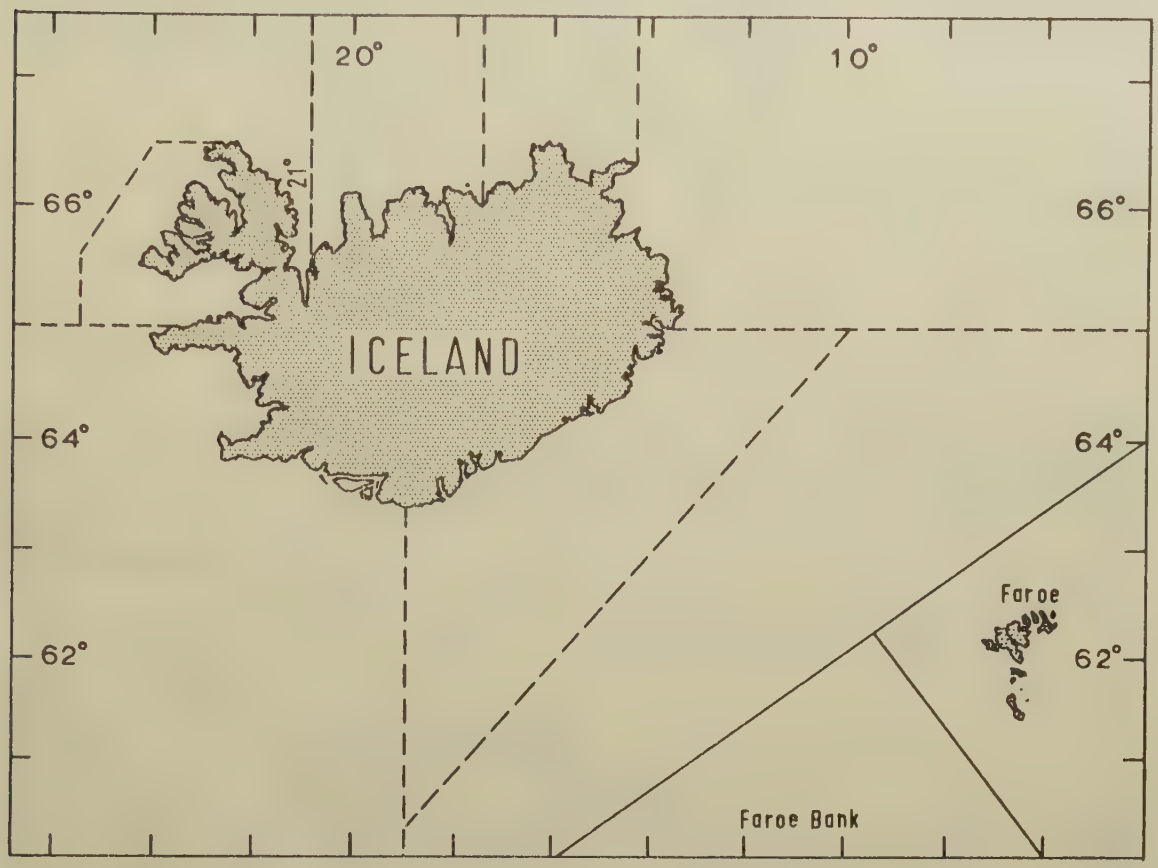
Weights of fish should be in metric tons, nominal weight. It is easy to convert them to this if they are not, so long as the units in which they were originally described are precisely stated. It is worth writing "nominal catch, metric tons" if that is what your figures are. If you write 'landings' it is worth saying that it is used in the sense described by FAO, (1973a) or if it is not say what sense is attached to it. 'Metric tons' prevents confusion with short (U.S.) tons'. These are apparently very minor points but their neglect causes scientists hours of work determining what published catch statistics really mean.

Conversion factors are used to raise quantities recorded on a landed weight basis to the live weight equivalent. Conversion factors (reflecting the "yield" rates) should be

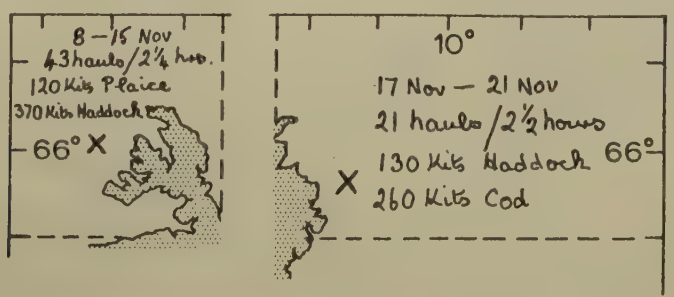
Name of Vessel .....

Date of Sailing .....197 Date of Landing 197.....

NORTH EAST ATLANTIC (I.C.E.S.) WATERS



It is well known that most of the important stocks of fish in the North Atlantic are being heavily fished. So that the Fisheries Laboratory can follow the fate of each stock, forecast the likely future trends in the abundance of the stock, and advise on conservation measures when necessary, it is essential to have the best possible information on present catches. In particular we want to know where (according to the area shown on the chart) and when the catches were made, what type of fish were caught, and the amount of fishing (number of hauls, and average length of haul). Would you please write this information on the chart in the appropriate position? For example, if the trip is split with 43 hauls at NW Iceland and 21 hauls at NE Iceland write:-



Where possible please indicate locality of greatest catch within areas:- X

Fig. 2.8(a) Chart of Fishing Grounds to be used for reporting by Fishing Skippers

NORTH EAST ATLANTIC (I.C.E.S.) WATERS

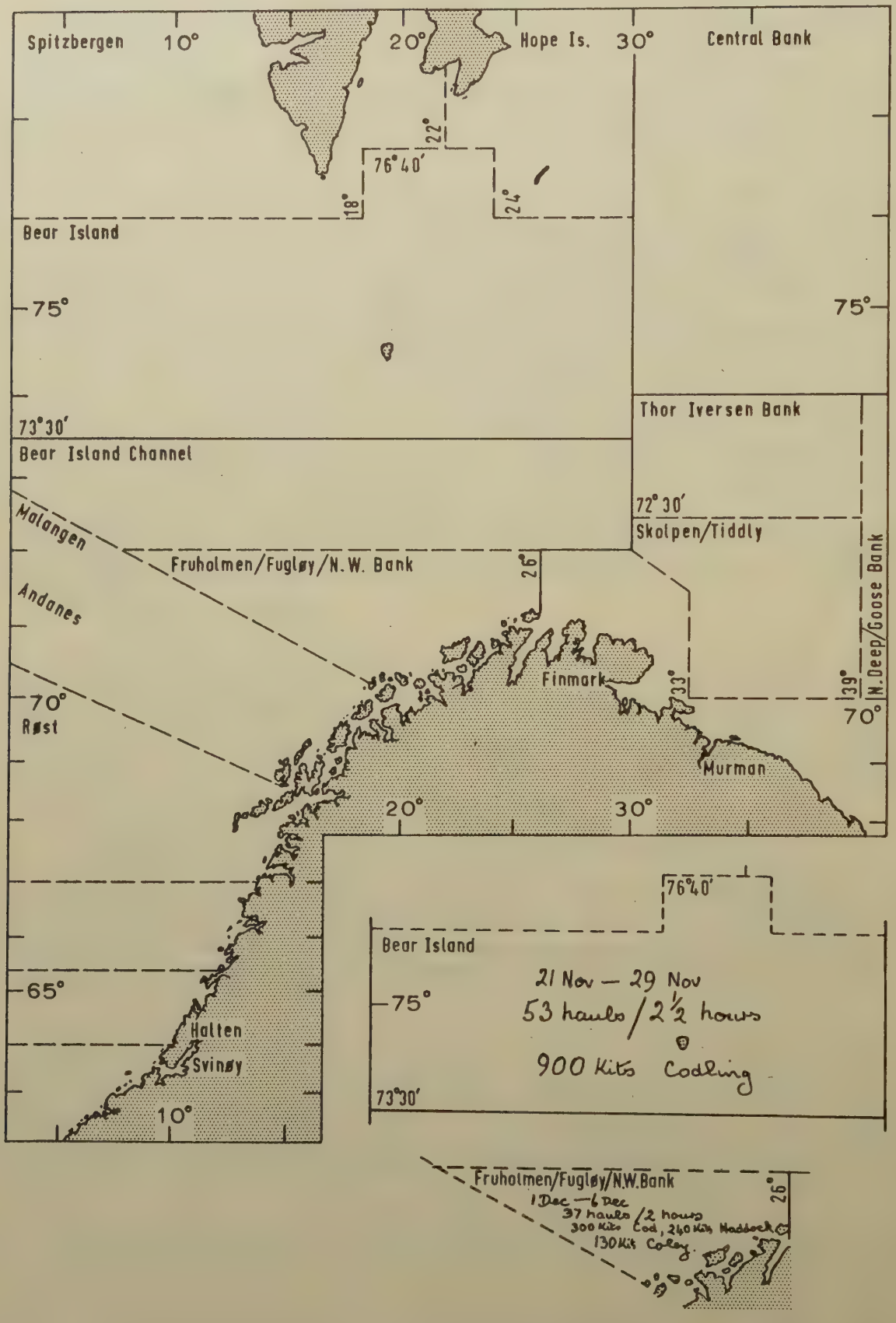


Fig. 2.8(b)

Name of Vessel	Day	1	
	Month and Year	2	
	Port	3	
Registered Letter and No.	Nationality of Vessel	4	
	Vessel No.	5	
Particulars of main fishing ground	Gross Tonnage	6	
	Registered Length	7	
Other fishing grounds	Method of Propulsion	8	
	Method of Capture	9	
	Region	10	
	Rectangle	11	
No. of lines or drift nets	No. of Hours Fishing	12	
	No. of Days Absent	13	
No. of hauls	No. of Voyages	14	
Average duration of haul	Serial No. (For Ministry Use only)		

		Code	Cwt.	£
Bream		1-01-0		
Brill	Large	1-02-1		
	Small	1-02-3		
	Unsorted	1-02-4		
Catfish		1-03-0		
Cod	Large	1-04-1		
	Medium	1-04-2		
	Small	1-04-3		
	Unsorted	1-04-4		
Conger Eels		1-05-0		
Dabs, Long Rough		1-33-0		
Dabs, other		1-06-0		
Dogfish		1-07-0		
Dory		1-08-0		
Eels		1-09-0		
Flounders or Flukes		1-10-0		
Gurnards and Latchets		1-11-0		
Haddock	Large	1-12-1		
	Medium	1-12-2		
	Small	1-12-3		
	Unsorted	1-12-4		
Hake	Large	1-13-1		
	Medium	1-13-2		
	Small	1-13-3		
	Unsorted	1-13-4		
Halibut	Large	1-14-1		
	Medium	1-14-2		
	Small	1-14-3		
	Unsorted	1-14-4		
Lemon Soles	Large	1-15-1		
	Small	1-15-3		
	Unsorted	1-15-4		
Ling		1-16-0		

Fig. 2.9(a)

Forms currently in use in the United Kingdom for recording landings

		Code	Cwt.	£
Megrims	Large	1-17-1		
	Small	1-17-3		
	Unsorted	1-17-4		
Monks or Anglers		1-18-0		
Mullet, Grey		1-35-0		
Mullet, Red		1-19-0		
Plaice	Large	1-20-1		
	Medium	1-20-2		
	Small	1-20-3		
	Unsorted	1-20-4		
Pollock		1-21-0		
Redfish		1-22-0		
Saithe (Coalfish)		1-23-0		
Skates and Rays		1-24-0		
Soles	Large	1-25-1		
	Medium	1-25-2		
	Small	1-25-3		
	Unsorted	1-25-4		
Torsk (Tusk)		1-26-0		
Turbot	Large	1-27-1		
	Small	1-27-3		
	Unsorted	1-27-4		
Whiting		1-28-0		
Witches	Large	1-29-1		
	Small	1-29-3		
	Unsorted	1-29-4		
Livers, Raw		1-30-1		
Liver Oils		1-30-2		
Roes		1-31-0		
All other		1-32-0		
Total Demersal				
Herrings		2-51-0		
Mackerel		2-52-0		
Pilchards		2-53-0		
Sprat		2-54-0		
Horse Mackerel		2-55-0		
Silver Smelt (Sparling)		2-56-0		
Whitebait		2-57-0		
Total Wet Fish				
Crabs		5-71-0		
Crayfish		5-72-0		
Lobsters		5-73-0		
Norway Lobsters		6-81-0		
Prawns		6-82-0		
Shrimps		6-83-0		
Cockles		6-84-0		
Escallops and Queens		6-85-0		
Mussels		6-86-0		
Periwinkles		6-87-0		
Whelks		6-88-0		
Squids		6-90-0		
Oysters (Hundreds)	Native	5-74-1		
	Mixed	5-74-2		
	Portuguese	5-74-3		
Total Value				

Remarks:

Fig. 2.9(b)

Ministry of Agriculture Fisheries and Food.

Return of fish landed.

N/L

Section A

Port MILFORD HAVEN 8 0 1 N/L

Name of Vessel N/L

Registered letter and No. and Nationality N/L

Date of landing N/L

Days absent N/L

No. of grounds fished N/L

Section B

Particulars of fishing ground	Main grounds	2nd. ground	3rd. ground	4th. ground	
Region	1				N/L
Rectangle	2				N/L
Method of capture	3				N/L
No. of hauls or shots	4				N/L
Av. duration of haul	5				N/L
Days or % of fishing	6				N/L
Rejection	7				N/L

R = Rejection, X = No Rejection, N = No Information

Section C

Species code	Rejected	est. qty Landed	Rejected	est. qty. Landed	Rejected	est. qty. Landed	Rejected	est. qty. Landed	
									N/L
									N/L
									N/L
									N/L
									N/L
									N/L
									N/L
									N/L
Z Z Z									N/L

If only one ground was fished, rejection figures only are required.

Unit of qty.

1 = Kitt
2 = %
3 = Baskets
4 = Stones
5 = Cwt.
6 = Crans
7 = Numbers
8 = Lbs.
9 = Hundreds
10 = Blocks
11 =
12 =

Section D

To be completed only for pair fishing
Names of additional vessels

Registered letter & No. Nationality

N/L
N/L
N/L

Fig. 2.9(c)

Section E

Species	code	cwt	£	
UNSold	UNS	→	→	N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
CONdemned	CON	→	→	N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
SALters	SAL	→	→	N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
FREezers	FRE	→	→	N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
Animal Food Stuffs	AFS	→ → →	→ → →	N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
	END	→ → →	→ → →	N/L

Section F

Species	Code	cwt	£	
BriLL	BLL			N/L
CATfish	CAT			N/L
COD, large	CD1			N/L
,, medium	CD2			N/L
,, sprags	CD4			N/L
,, best small	CD6			N/L
,, small	CD3			N/L
,, unsorted	COD			N/L
DABs, other	DAB			N/L
DoGfish, Spurdog	DGS			N/L
GUrnards & Latchets	GUL			N/L
HADdock, large	HD1			N/L
,, small	HD2			N/L
,, unsorted	HAD			N/L
HAKe	HAK			N/L
HALibut	HAL			N/L
LEMon sole	LEM			N/L
LINg	LIN			N/L
MOnks or Anglers	MOA			N/L
PLAice, large	PL1			N/L
,, medium	PL2			N/L
,, small	PL3			N/L
,, chats	PL4			N/L
,, unsorted sml.	PL5			N/L
,, unsorted	PLA			N/L
POLlock	POL			N/L
SaiTHe, coalfish	STH			N/L
SKates and Rays	SKR			N/L
SOLes, large	SL1			N/L
,, small	SL3			N/L
,, unsorted	SOL			N/L
TURbot, large	TR1			N/L
,, small	TR3			N/L
,, marked	TR4			N/L
,, unsorted	TUR			N/L
WHitinG	WHG			N/L
WITches	WIT			N/L
ROEs	ROE			N/L
MiXed Demersal	MXD			N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
				N/L
TOTal	TOT			N/L

Fig. 2.9(d)

Ministry of Agriculture, Fisheries and Food

Methods of Capture — Code No. 2.0

TRAWLING	
Bottom trawling - 1 vessel	01
" " - 2 vessels	02
Nephrops trawling	06
Midwater trawling - 1 vessel	11
" " - 2 vessels	12
" " - 3 "	13
" " - 4 "	14
	15
Beam trawling - 1 trawl	21
" " - 2 trawls	22
" " - 3 "	23
SEINING	
Danish seining	26
Fly seining	27
Unspecified seining	28
Purse-seining - 1 vessel	31
" " - 2 vessels	32
" " - 3 "	
Ring-netting - 1 vessel	41
" " - 2 vessels	42
" " - 3 "	43
	44
	45
Drift netting	46
Trammel netting	47
Tangle "	48
Hoop "	49
Stake " access by boat	50
" " " " land	51
	52
Shank " towed by boat	53
" " " " tractor	54
	55
Eel traps	56

DREDGING	
Hand dredging	60
Power "	61
Suction "	62
	63
POTTING	
Pots, top-opening	65
" , side-opening	66
" , other or mixed	67
LINING	
Lines (by numbers of hooks in 100s)	70
Lines (by number of lines)	71
Lines hand-held, feathering	72
	73
	74
Hand picking, access by boat	75
" " , " " land	76
" " , divers	77
FOR H-FORMS	
Foreign carriers	100
INDUSTRIAL FISHING	

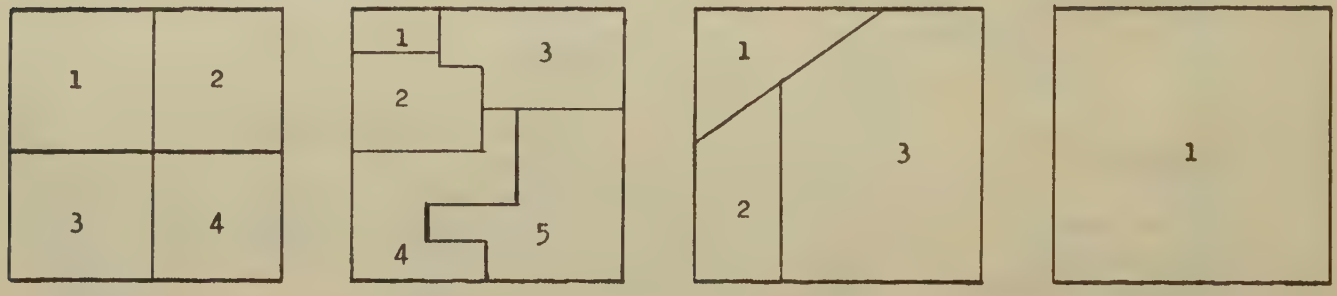
When the gear used is known to be specifically for Industrial Fishing ADD 100 to the above codes, e.g. industrial pair-trawlers, midwater trawl, Code = 112

Fig. 2.9(e) Coding System for Fish-capturing Methods used in the United Kingdom

compiled by all national offices and kept under constant review. They might have to be revised from time to time due to changes in the size composition of catches, the handling and processing etc. It is important to see that these conversion factors are kept standard to a set number of decimal places; when dealing with large landings a change in the third decimal place can cause a big difference in the end result. A record of them should be published and also a record of when they are changed.

The difficulties of combining data from several nations which have not used the same statistical breakdown of areas of fishing are obvious. At the minimum the statistical squares used must correspond to the distribution of the stock but a better understanding of a fishery can usually be obtained if smaller areas of fishing are used. But, they must be standardized to be useful. Fig. 2.7 shows an example of four nations each with its own divisions of a fishing subarea based upon a stock. The difficulties, say, of analyzing north-south movements from combined information are obvious. The example is hypothetical but it corresponds very closely to the situation for North Sea data on demersal species.

Fig. 2.7 Example of different divisionbreakdowns of the same subarea by four nations



It is very rarely possible to collect fishing effort data in an internationally-agreed standard manner because nations' fleets differ. To data, this has proved an unsoluble difficulty to conserving fisheries by regulating fishing effort.

2.11 References

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APPENDIX 2.1

EXAMPLES OF COLLECTION OF CATCH AND EFFORT DATA

There are many ways of collecting information on catch and effort. Obviously, totally different systems must be organized to meet widely differing conditions. For example, a large freezer trawler may land once every three months at a major port in Europe but a canoe fishing with a drift net may land every day at an isolated village in Africa.

The number of staff available to undertake the work, and also their capability, will vary, and so the collecting programme must be designed to meet the existing local circumstances.

The following three examples are used to illustrate some of the methods that can be employed to cope with a variety of situations:

1. landings centred at major ports, e.g. United Kingdom
2. an African lake fishery
3. a purse-seine fishery.

1. A demersal fishery landing at a major fishing port

This section describes the methods used when the landings of a fishery are concentrated at a small number of major ports at which ideal conditions exist for the collection of an accurate and complete set of catch and effort data. The methods used to collect landings' statistics can be conveniently split into two types, each providing a different problem:

1. wet fish landings, where the fish are preserved in ice after being caught; the maximum duration of this type of fishing voyage being usually about 21 days;
2. frozen fish landings, where the fish are frozen on board the catching vessel either whole, or after immediate processing; the duration of voyage can extend up to six months.

1.1 Wet fish landings

It is assumed that the wet fish landings occur at a fixed time each day and that a staff of collectors based at the port can collect by direct observation all the necessary information. The weight and species of all the fish being landed can be seen and recorded together with details of the type of fishing gear used to take the catch. The skipper or crew members of the vessels are interviewed to collect details of the area fished and the amount of fishing that has been done during the trip. Any other relevant information, for example, rejection of small fish etc., is also obtained during the interview. The value of the fish landed is obtained by attending the sales.

This system produces the required results with very little help from the industry other than the willingness of the skipper or crew to reveal details of the fishing operation, but it obviously requires a great deal of effort by the port-based collecting staff. There are usually a number of acceptable short-cuts available, provided that some form of cross-checking is built into the system to ensure that there is no loss of accuracy.

The most useful of these short-cuts is the use of sales notes to provide information on weight and value of catch. Almost all fishing companies produce, for each vessel on the day of landing, a detailed sales note giving the total catch and value of each species landed. In some countries it is a statutory requirement for fishing firms to supply this information, but often the exchange of information can be arranged informally rather than by enforcement.

This usually results in an improvement in the quality of the data and a much closer understanding between the industry and the scientist. The choice of a formal or informal arrangement depends very much on the local conditions and the relationship of the government with the industry.

An alternative method to interviewing the skipper and crew to collect details of fishing operations is to provide a log sheet for completion at sea by the skipper during the fishing operations. Examples based on divisions of fishing areas by grounds are shown in Fig. 2.8a-b. In theory these log sheets provide the most detailed information, but there are many practical problems to be faced. While fishing, skippers are usually too busy to complete a log and much of the contents may be written from memory much later. Log sheets are often forgotten completely or, if not collected from the vessel, are taken back to sea and lost. A log sheet system can be made to work very efficiently but it requires a continued follow-up. It is greatly helped if the log sheet is designed so that a copy be kept by the skipper in a form that he finds useful.

1.2 Frozen fish landings

These present special problems because freezer trawlers make long voyages often to a number of different fishing areas. The mechanized landing of frozen blocks extend over many days and makes it impossible to collect quantities by direct observation. The information on landed weights must be obtained from the trawler owners. Fishing effort can be obtained only with the cooperation of skippers and owners. Log sheets in the form of a chart of the fishing areas (Fig. 2.8a-b) have been used in English trawlers. Some fishing companies require their skippers to complete a detailed fishing log, which may be used to get fishing effort information.

1.3 Recording forms

The forms used in England and Wales for recording weights of fish landed are shown in Fig. 2.9. The form shown as Fig. 2-9c-d has been designed so that the data recorded on it can be given to a punch operator who prepares the paper or magnetic tapes which are used in computer processing. It allows information about fishing effort on four different fishing grounds to be recorded together with information on the breakdown of catch by grounds and also the quantities of fish of different species landed (Fig. 2.9d). The form is complicated because it has been designed to be used to record information on the many different fishing operations in England and Wales.

2. An African lake fishery

This section is based on the problems of collecting statistics of a fishery which is operated mainly by small units, often a single boat and its crew, landing at numerous and scattered sites and selling through, at best, a loosely organized marketing system. Such a fishery is typical of many African lakes. The problems of collecting statistics in such a fishery are mainly organizational. Although the basic statistics are still those of catch and effort, it is usually a question of how to deploy the available manpower to collect these most effectively. This section therefore deals not only with all of the statistics which can be collected at first sale or its equivalent, but with the collection and use of statistics obtained at other points along the distribution chain.

2.1 Collection of basic data

In order to make assessments in a gill-net fishery it is usually necessary to have much more knowledge about the gear in use than in any other type of fishery, because a gill-net is highly selective. Therefore, in collecting statistics it is essential, if possible, to stratify the catch by mesh-size of nets, unless the only information which is required is total catch.

The basic data that need to be collected are:

area fished
time spent fishing
type of boat

Type of boat	Licence No.		
Mesh size	$1\frac{1}{2}$ inches	2 inches	3 inches
Number of nets	10	15	7
Species	No. Weight	No. Weight	No. Weight

This is only a suggested layout for a form for recording catches.

2.2 Landings

(i) Weight recorded at landing site

(a) Sorting and grading before sales. Although unusual, catches may be sorted into species and sold in standardized containers. This simplifies the task of obtaining data of total catch, by species, but it may make it very difficult to relate catch to the mesh-size of the gill-net in which it was caught. If sorting by categories occurs, category size may be closely related to mesh-size, especially for the smaller mesh-sizes.

(b) No sorting or grading before sales. A more probable situation is that each boat owner sells his catch direct to a fish buyer and that there is no sorting before this transaction. In this instance the required information can be obtained by a collector of statistics who is especially appointed for this purpose and whose duty it is to meet every landing. When landings are numerous it may not be possible to sample every boat, in which case a subsampling programme must be used. Every nth boat (for example 1st, 4th, 7th, 10th etc.) is sampled and the sampled landings raised by N/n, where N is the total number of boats landing. This method will avoid the tendency to sample the boats with the smallest catches (bypassing those with large catches), and to ignore those with no catch at all.

A subsampling routine will also cover those instances in which a major fishing community is surrounded by several minor ones, at which it is impractical to station a collector of statistics. In this case it is necessary to allow for the possibility that a proportion of the boats from each community are not used for fishing and that this proportion is unknown.

- Let the number of boats sampled in the main community = n
  the total number of boats landing fish in the main community = N
  the total number of boats in the main community = M
  the total number of boats in the minor communities = m
- and the mean weight landed by each sampled boat = w
  total weight landed in the main community = Nw
  proportion of boats fishing in the main community = N/M
  estimated proportion of boats fishing in the minor communities = $\frac{Nm}{M}$
  estimated total weight landed by all the communites = $\frac{Nmw}{M} + Nw$
  $= Nw(1 + \frac{m}{M})$

The ratio N/M could be taken on a monthly basis, whereas (m) could probably be assessed less frequently. The boats of the minor stations should fish the same areas as those of the major stations, otherwise (w) is unlikely to be the same. If more than one type of boat is in use the calculation needs to be made for each type separately. The best method in which to employ staff is to ensure that sampling at the major stations is continuous throughout the year, deploying extra staff to the minor stations as they are available.

The choice of which communities to sample is best made by giving each of the communities a number and then using a table of random numbers (see section 2.6.1) to determine which will be visited. This avoids bias that might result from access to some villages being easier than others or pleasanter relationships existing with one than another.

2.3 Weight recorded away from the landing site

The fishing communities may be so transitory, inaccessible or scattered that it is impossible to have collectors working on the above basis. In such instances it may be possible to collect statistics of total catch away from the point of first sale only. In the type of fishery under consideration, often the total catch eventually has to be transported along a few routes, which are monitored for various reasons at check-points, for example, road barriers, rail terminals, customs' point. These check-points form an ideal post at which to assess the total catch. Taking a road check-point as an example, a sampling programme can be based on the following factors:

i) average weight of fish in a package
ii) average number of packages per lorry
iii) average number of lorries passing check-point per unit of time.

In order to assess the species' composition it will be necessary, at some stage, to sample packages in order to estimate their average species' composition. Packages may not always have the same species' composition; for example, dissimilar species may never be mixed, and so it may be necessary not only to estimate how many packages of each species' group are being carried by a lorry but also how the proportions of these packages vary seasonally. As it may not be possible to examine packages from the lorries, species' composition may have to be estimated by special visits to the lake, from time to time, and this information applies to that collected at the check-points. To the total figure obtained it is necessary to add some estimate of local consumption. If this is not done the results are likely to be biased because the fish sent by lorry are likely to be those of highest value. This total catch information cannot be related directly to the mesh-size of the gill-nets in which it was caught.

2.4 Total effort

The basic unit in a gill-net fishery is the gill-net, and there are several methods which can be used to assess the total number of nets fished.

In fishing communities in which collectors of statistics are based the number of nets fished can be assessed by:

(i) counting the number of nets of each mesh-size when the total landing is recorded; this can be done by subsampling if necessary as for sampling total landings (section 2.2 - this appendix)
(ii) sampling at intervals: at given intervals the number of nets fished by a sample of boats is counted and the average number of nets per fishing unit calculated. This, multiplied by the total number of fishing units, gives the total number of nets being fished. The number of fishing units may be determined by:

(a) direct census on the ground, which involves problems of access;
(b) licensing, which involves problems of avoidance;
(c) aerial survey, which has no problems of either access or avoidance and is therefore usually quick and easy.

Fishing units need to be divided into different categories depending upon their average net-carrying capacity. In 1961-62 two main types of vessels fished on Lake Sesseseku (Lake Albert), dugout canoes and various designs will constructed hulls. The latter could carry up to five times as many gill-nets as the former. An aerial canoe count gave the potential fishing effort of the canoes on the lake because that of the vessels with constructed hulls was five times that of a dugout canoe. When fishing was good and every fisherman could buy as many nets as his vessel could carry this comparison was valid. When fishing was poor the number of nets carried depended upon the money which the fisherman had available. In these conditions the comparison was not necessarily valid. Motive power needs to be considered if it affects fishing efficiency.

It may not be possible to count the number of nets in use directly at any stage; for example, nets may be left fishing continuously and visited only to remove the catch. An indirect census of the number of nets in use can be made if it is possible to identify the retail outlets from which sales of nets used in a given area are made. Sales figures of nets give an index of the number of nets fished in the lake, and are even more useful if the average life of a gill-net is known.

Many factors affect the fishing power of gill-nets, some of which are:

1. Mesh size: Because a gill-net is a very selective fishing gear its catch will depend greatly on its mesh-size. Measurements of mesh-size should always be defined as referring to either bar size - the distance between two adjacent knots - or stretched mesh-size - the distance between the centres of two opposite knots in the same mesh when fully extended along the pull of the net (the N-direction in the terminology of the International Standards Organization). For knotless nets this measurement is the distance between the centres of two opposite joints in the same mesh when fully extended along its longest possible axis.

2. Net material: the fishing power of a gill-net can vary markedly with the type of net material, the difference between multifilament and monofilament nylon gill-net being probably one of the best examples.

3. Knotted or knotless: generally this is linked with (2), monofilament nets usually being knotless, but not necessarily so, and multifilament nets knotted.

4. Size of net: this is best defined as the number of meshes in each direction, but this is a difficult statistic to collect if the gill-nets are machine-made and sold in standard sizes, so that a gill-net of a given mesh size will always be this standard size, it will be unnecessary to record the size of the net; all that is needed is the number of nets in the fleet, which defines its length. However, nets may be joined vertically. If some fishermen adopt this practice and others do not, then it may be necessary to record the total number of standard nets in a fleet and whether these are mounted horizontally or vertically, although a fleet of 10 standard nets (sn) in length by 2 sn in depth is unlikely to have the same fishing power as a fleet which is 20 sn long by 1 sn deep. The situation is often simplified by the depth of the nets becoming standardized toward the optimum, for example, to fish the whole water column from surface to bottom in shallow water. Depth of net is not then important.

5. Hanging ratio: this is defined as the ratio of the length of headline occupied by the net, if it were mounted with the meshes square, to the length of the headline occupied by the nets as actually mounted. The fishing power of a net can be altered considerably

by changing its hanging ratio, but usually this standardizes toward the optimum and can be ignored. It is a difficult statistic both to collect and to incorporate into analyses.

6. Colour: there are records of variations in catch rates with net colour.

7. Number of boats in the fleet: if the fleet has to search for fish which form compact shoals, the searching efficiency will increase as the size of the fleet increases. On the other hand, as the size of the fleet increases, the chance that every boat in the fleet will be able to fish in the area of maximum abundance decreases and the fleet will become less efficient with size.

8. Area of fishing: this may need to be more closely defined than simply geographically or by small statistical squares. For example, in a lake fishery a fisherman may have the option of fishing in sheltered lagoons or close inshore or well offshore. In each of the last two areas he may have a further choice of using either floating or bottom set gill-nets. This gives a variety of fishing possibilities all of which will yield catches with a different species' composition. In addition to this there may be physical dissimilarities between different parts of the lake, which may be associated with population differences. As far as possible, the sampling programme should be stratified to take these into account.

9. Intervals between hauling: total fishing power will depend upon the number of time periods a net is fished. A time period is very often one night, the nets being shot one evening and hauled the next morning, so that a net-night becomes a standard fishing unit. However, nets may be visited less frequently and a net fished for two nights between visits is unlikely to fish as efficiently as one which is visited and cleared after each night. The problem is usually not very important because the method of working the nets generally standardizes toward the optimum, especially where deterioration of the catch is rapid.

2.5 Catch per-unit-effort

The methods of obtaining catch per-unit-effort depend upon the methods which are used to determine both catch and effort. Ideally, the best method is to have collectors of statistics at the major landing sites, collecting accurate catch and effort statistics on a fishing vessel unit basis. Total effort can usually be assessed fairly accurately by means of fishing vessel censuses, and total catch then determined indirectly from the product of total effort and catch per-unit-effort.

As with all catch and effort statistics, the catch must refer to the unit of effort responsible for that catch. In a gill-net fishery there is the complexity that very often nets of different mesh-sizes are being fished. As stated previously, gill-nets are very selective, so it is essential, if possible, to determine how many nets of each mesh-size are being used in a fishery if proper assessments are to be made.

Tables 2.4a-b set out the type of sampling programme which may be called for in a gill-net fishery. It does not cover all the possible complexities.

3. A purse-seine fishery

The most striking development in catching methods over the past ten years has been the great advance made in aimed fishing techniques. Purse-seining and midwater trawling are dependent upon fish shoals being found by echo-sounders and sonar and the fishing gear being aimed at a particular shoal or group of shoals. The problems of collecting data from both purse-seiners and midwater trawlers for use in stock assessment are therefore quite similar.

A profitable commercial purse-seine or midwater trawl fishery is dependent upon an abundance of midwater shoals. In the majority of cases the catches of pelagic species by purse-seine are used for reduction to meal and oil. As the price for the raw material is necessarily low, and quite often fixed, this means that the purse-seine fleets must catch large quantities as quickly as possible. There is, therefore, every incentive for cooperation between individual vessels in the fleet to cut down searching time and also to seek techniques which increase the catching efficiency of the vessels (e.g. power blocks and pumping which minimize the time spent getting the catch aboard and allow more time to be spent searching.

The abundance of demersal fish caught by bottom trawls is estimated by using a simple "catch per fishing time" type of expression. This statistic implies that the number of fish caught are simply related in some ways to the area swept by the trawl, the catch being dependent more on the characteristics of the fishing vessel and its gear than on the behaviour of the fish. In contrast, the gill-net fishery is more dependent on the behaviour of the fish, the gear itself being more or less passive. The catch of a purse-seiner or midwater trawler is to a far greater degree dependent on the expertise of the skipper. The absolute magnitude of the catch might bear little relationship to the true abundance of the stock in the area.

3.1 Collection of basic data

Because catching is divided and because fishing skippers cooperate, the type of effort data collected must reflect changes in sizes of vessels operating, changes in gear and some estimate of the time spent searching for shoals.

The following data on fishing vessels is needed and any changes taking place must be recorded:

(a) name of vessel:
(b) length:
(c) hold capacity:
(d) engine (bhp):
(e) equipment:
    1. echo-sounder
    2. sonar
    3. size of net
    4. power block
    5. fish pump
    6. radio telephone
    7. direction finder
    8. radar.

Length and engine power reflect the distance from port an individual vessel is able to fish. Hold capacity gives a criterion for judging whether the catch landed might be considered as an abundance index. For example, in recent years in the Peruvian anchoveta fishery a common hold capacity is about 200 tons; catches bigger than this are often made with the purse-seine and the extra fish are either released or given to another vessel. Thus on any one day many vessels may enter Peruvian ports with full holds. The catches per landing of these vessels bear no relation to the abundance of fish in the sea; however, the number of vessels with full holds might well be the index of relative abundance. Catch per ton of hold capacity per landing affords a more useful estimate of the extent of vessels fishing to saturation point. It is in this measure that the degree of expertise of individual skippers becomes apparent. Often the fully loaded vessels are the same ones in each daily landing.

In a developing fishery the acquisition of better vessels with sonar and power blocks has led to an increase in net size. Fish pumps have been installed to ease handling and these allow more shots to be made each day. Radio telephone and direction finders help to make the fleet a more efficient searching unit, and the addition of radar allows fishing in poor weather conditions and more accurate navigation to the locations of suitable fish shoals.

3.2 Catch data

Because most outlets for purse-seine-caught fish are bulk handled, it is possible to get catch information in two ways. The catch, as estimated by the skipper or mate, can be obtained by interview, together with other relevant information. Alternatively the weight of the catch paid for by the factory can be obtained but this may be much less than the fishing skipper's estimate which in turn may be either higher or lower than the actual catch. For small pelagic fish, such as the Peruvian anchoveta, differences as much as 20% are found. Losses occur in transferring the catch from the hold to the factory; these losses occur through pumps, elevators, and general deterioration of the fish by being held in bulk. If many vessels land it might not be possible to interview all skippers and both methods should be used.

To interpret catch data as an index of stock in a developing fishery, information on the geographic distribution of the stock (or catch) is essential. Daily information on the fishing positions of each vessel is desirable. With fleets of purse-seiners operated by companies, daily reporting to the company office by the skippers is often the rule, in which case it may be possible to obtain this information.

3.3 Effort data

It is sometimes said that it is impossible to use purse-seine catches for estimating the abundance of a fish stock. This may well be true if catch per landing is considered because a purse-seiner stays at sea until its hold is as full as possible. Searching time must be taken into account in a purse-seine fishery and as the abundance of fish shoals becomes scarce the importance of searching time and of cooperation between fishing skippers becomes greater.

The number of purse-seine shots made could be another estimate of fishing activity. However, this measure too is influenced strongly by the efficiency of the skipper in interpreting the sonar record and making the cast correctly in relation to the movement of the fish shoal.

Because the interpretation of purse-seine effort is complex it is important to collect in detail the time spent in each part of the fishing operation:

Total length of trip
Number of shots
Time handling gear - shooting, hauling, emptying net etc.
Steaming time to and from fishing grounds
Searching time on the fishing grounds.

If this breakdown of effort information is available then it will be possible to interpret the data more effectively.

3.4 Catch per-unit-effort

As has been repeatedly stated, with purse-seine vessels, the main problem in deriving an index of abundance is the directed nature of the fishing operation. In the Peruvian anchoveta fishery the abundance index used has been catch per gross registered ton of fleet capacity per month or day. The gross registered tonnage of a vessel summarizes a number of characteristics of the vessel, such as length, engine power etc. Various methods may be used to calculate this parameter in problems of comparison.

It is seldom possible to recommend a single best method of expressing catch per effort for purse-seiners; perhaps the simplest of catch per ton of hold capacity per hour at sea offers an estimate which includes a ship characteristic and some estimate of fishing/searching time. However, it should be remembered that the fisheries' scientist must look at the abundance index on a long-term basis for studying the effect of fishing on the stock. As fisheries develop their efficiency, the area of exploitation of the stock may increase. In the early 1960's the Peruvian anchoveta catch was taken mostly within 15 miles of the coast; by 1970 the area of exploitation extended out to 60 miles and to areas to the north and south of the original fishing areas. Perhaps catch per ton of hold capacity per unit area fished, would give a reliable estimate of abundance if suitable data had been collected in early years.

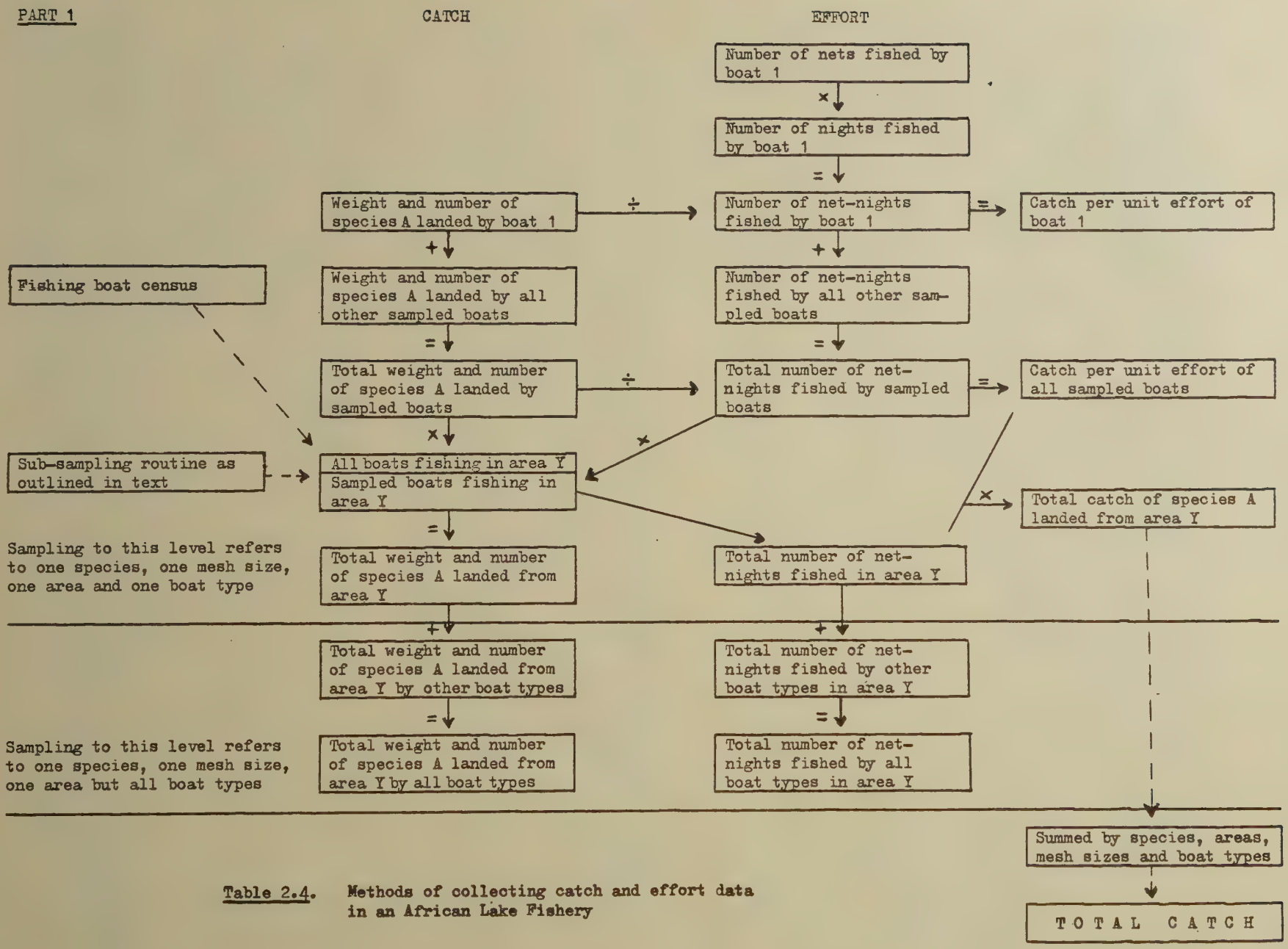
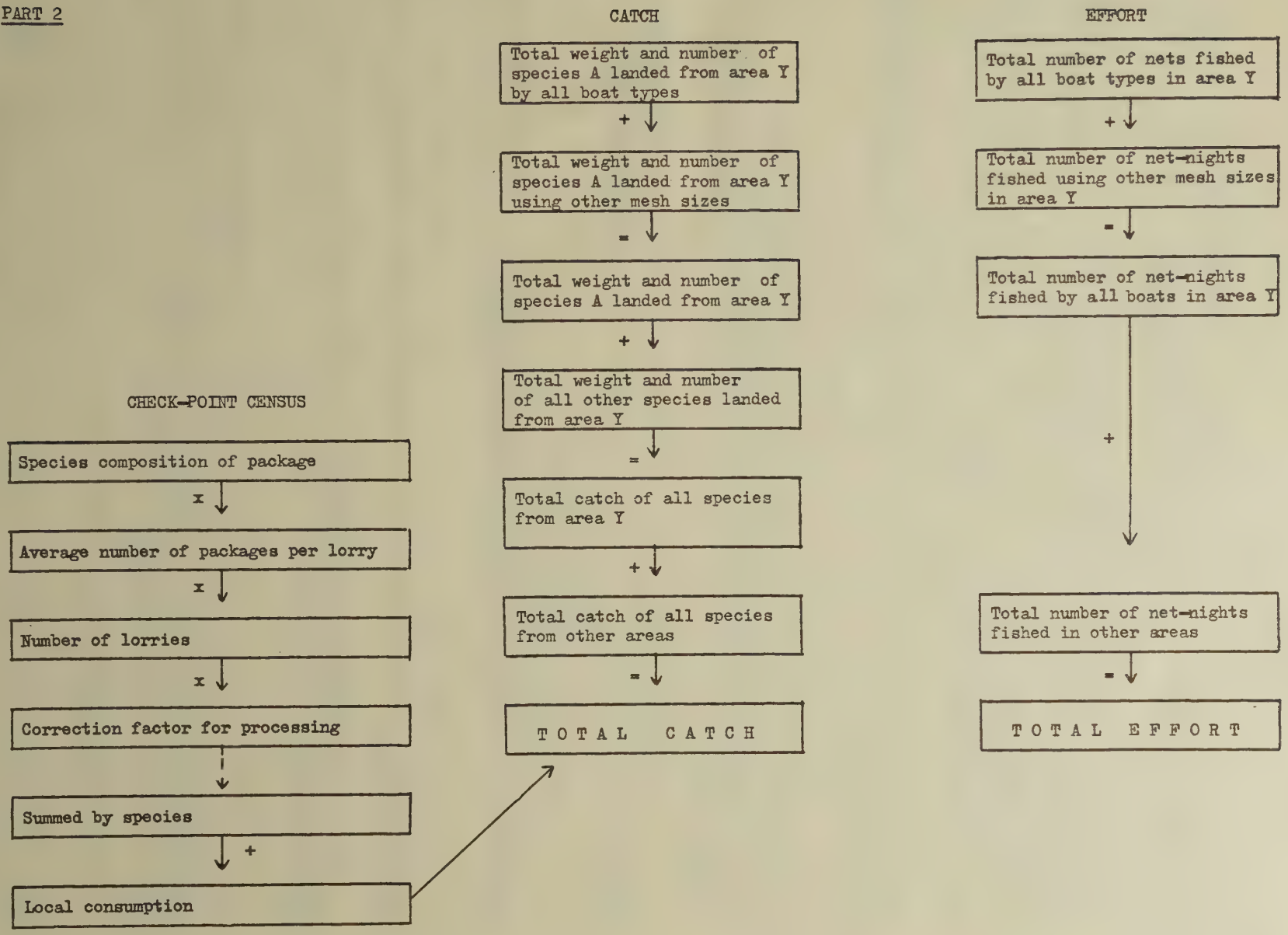

PART 1
CATCH
EFFORT
Number of nets fished by boat 1
Number of nights fished by boat 1
Weight and number of species A landed by boat 1
Number of net-nights fished by boat 1
Catch per unit effort of boat 1
Fishing boat census
Weight and number of species A landed by all other sampled boats
Number of net-nights fished by all other sampled boats
Total weight and number of species A landed by sampled boats
Total number of net-nights fished by sampled boats
Catch per unit effort of all sampled boats
Sub-sampling routine as outlined in text
All boats fishing in area Y
Sampled boats fishing in area Y
Total catch of species A landed from area Y
Sampling to this level refers to one species, one mesh size, one area and one boat type
Total weight and number of species A landed from area Y
Total number of net-nights fished in area Y
Total weight and number of species A landed from area Y by other boat types
Total number of net-nights fished by other boat types in area Y
Sampling to this level refers to one species, one mesh size, one area but all boat types
Total weight and number of species A landed from area Y by all boat types
Total number of net-nights fished by all boat types in area Y
Summed by species, areas, mesh sizes and boat types
TOTAL CATCH

Table 2.4. Methods of collecting catch and effort data in an African Lake Fishery

PART 2


CATCH
Total weight and number of species A landed from area Y by all boat types
+
Total weight and number of species A landed from area Y using other mesh sizes
=
Total weight and number of species A landed from area Y
+
Total weight and number of all other species landed from area Y
=
Total catch of all species from area Y
+
Total catch of all species from other areas
=
TOTAL CATCH
EFFORT
Total number of nets fished by all boat types in area Y
+
Total number of net-nights fished using other mesh sizes in area Y
-
Total number of net-nights fished by all boats in area Y
+
Total number of net-nights fished in other areas
-
TOTAL EFFORT
CHECK-POINT CENSUS
Species composition of package
x
Average number of packages per lorry
x
Number of lorries
x
Correction factor for processing
Summed by species
+
Local consumption

APPENDIX 2.2

NOTES ON FISHING EFFORT STATISTICS

This appendix is taken from FAO Fisheries Circular No. 429. It describes methods of recording fishing effort statistics as recommended by FAO.

1. Fishing Time

(a) No. of hours or 1000 hooks fished

No. of hours fished: for otter trawls this is defined as "the total number of hours during which the trawl was on the bottom and fishing"; if countries are unable to report so precisely they should give the nearest approximation with the precise definition of the approximation used.

No. of hours fished: for dory vessels this is defined as "the number of hours the dory fleet is absent from the mother vessel times the number of dories".

Thousands of hooks fished: this is defined as "the number of hooks used in each set times the number of sets". This figure should be calculated to the nearest thousand hooks.

For other fishing gear: the number of hours the nets, seines, traps, pots, dredges, harpoons etc. were used in the fishing operations; this is the product of the number of hours per unit times the number of units.

(b) No. of hauls, drags or sets made

The number of times the fishing gear has been hauled or dragged or set, whichever description is appropriate to the fishing gear or technique used.

(c) No. of days fished

The number of days (24-hour periods, reckoned from midnight to midnight) on which any fishing took place.

For those fisheries in which searching is a substantial part of the fishing operation, days "on grounds" in which searching but not fishing took place, should be included in the days fished data.

Taking into account the inclusion of "searching time" the definition of "number of days fished" could be further refined at the national level if possible as follows: "The number of days (24-hour periods, reckoned from midnight to midnight) on which the fishing craft was on the fishing grounds, intent on catching fish (not counting the time spent steaming to or from port and between grounds) minus the number of fishing days lost through delays from weather, breakdown or other factors".

(d) No. of days on grounds

This is defined as the number of days (24-hour periods, reckoned from midnight to midnight) in which the craft was on the fishing ground, and includes in addition to the days fishing and searching also all the other days while the craft was on the ground.

(e) No. of days absent from port

The number of days absent from port on any one trip should include the day the fishing craft sailed but not the day of landing.

Where it is known that fishing took place on each day of the trip the number of "days absent from port" should include not only the day of departure but also the day of arrival back in port.

Where on any trip a fishing craft visits more than one "fishing area" (as defined for statistical purposes) an appropriate fraction of the total number of days absent from port should be allocated to each "fishing area" in proportion to the number of days spent in each, so that the total number of days absent on any trip will be the sum of the number of days allocated to all of the different "fishing areas" visited.

(f) No. of trips made

Any voyage during which fishing took place in only one "fishing area" is to be counted as one trip.

When in a single trip a craft visits more than one "fishing area" an appropriate fraction of the trip should be apportioned to each "fishing area" in proportion to the number of days spent fishing in each, so that the total number of trips for the Statistical Area as a whole will be the same as the sum of trips to each "fishing area".

2. Fishing Power

(a) Average gross tonnage

Average gross tonnage is to be given in gross registered tons.

The averages should be weighted. Weighted averages are required in view of the decision to reduce the reporting task of the national offices by eliminating for the time being the monthly breakdown of the annual effort measure data.

(b) Average horse-power

Data should be given in "brake horse-power". For steam engines give the data instead as "indicated HP".

The HP averages should be given as straight i.e. unweighted averages, or as weighted averages, with an indication of the type of average used. Weighting is to be calculated on the basis of "number of trips".

(c) Average length, overall

The overall length should be given; if this is not possible and if the registered length is substituted the word "overall" in this line is to be deleted and "reg" inserted. The length data should be given in metres (1 British foot = 0.3048 m).

These length averages should be given either as straight (unweighted) averages or as weighted averages with an indication of the type of average used. Weighting is to be calculated on the basis of "number of trips".

(d) No. of fishing units operating

The number of fishing units operating should inlcude every unit within the relevant "class of fishing units" that fished at least once in the fishing area.

In the case of "pair boat" fisheries the two craft together comprise one fishing unit.

3. General Remarks on Priority in Providing Data on Fishing Effort

For detailed standard definitions of the various types of effort see sections 1 and 2 of Part D.

Countries are asked to indicate in separate memoranda the extent to which the effort data provided on the reporting forms comply or deviate from these detailed standard definitions.

According to the priorities indicated below in sections 3.3 and 3.4 national reporting offices are requested to provide the data relating to the appropriate types of fishing effort.

In giving data on fishing time effort measures, the following desirable priorities are to be followed:

First priority: either "no. of hours fished" or "1000 hooks fished" should be provided; in addition, "no. of hauls, drags or sets made" should also be given.

Second priority: "no. of days on ground" and "no. of days absent from port".

Third priority: "no. of trips made".

In giving data on fishing power effort measures, the following desirable priorities are to be followed:

First priority: "average gross tonnage" (see section 2.1)

Second priority: "average horse-power" (see section 2.2)

Third priority: "average length, overall" (see section 2.3)

Fourth priority: "no. of fishing units operating" (see section 2.4)

In addtition, national offices are also to indicate the extent to which effort data provided were not recorded but were obtained by sampling.

3. THE MEASUREMENT OF FISH AND SHELLFISH

Measuring the linear dimensions of whole or parts of fish is probably the most widely used technique in fisheries biology studies. Of the many observations that can be made, the one that is most frequently chosen is that of total length because it is quick and easy to measure. Total length is usually closely related to many of the other factors such as weight, age and maturity so that any of these may be easily determined, from the length data used, with a small key sample relating length with the factor concerned. Length data collected from a developing fishery are particularly important; other biological studies can be made later, but measurement of sizes in the early days can be done only at that time and therefore should be given a high priority when a programme of investigation is being planned.

3.1 The Measurement of Fish

3.1.1 Choice of length dimension to measure

The choice of which length dimension to measure is arbitrary. Most fisheries biologists measure either fork length or total length but neither method has a clear advantage over the other sufficient to recommend its acceptance as a universal standard. However it is highly desirable that the same unit should be used by all those measuring fish from the same stock.

Damage to the tip of the tail can make it difficult to measure total length, but it can be as difficult to measure fork length when the tail is frayed and the fork is not well defined.

In most cases it is easiest to measure total length but for some large species with a rigid, deeply forked caudal fin, fork length is preferred. There is general agreement among tuna workers to measure the fork length. (Report of the FAO Expert Panel for the Facilitation of Tuna Research, Working Party on Tuna Length Measurements and Tabulation). The West African institutes concerned with the international Sardinella investigations in the East Central Atlantic have also adopted fork length as the standard dimension. On the other hand, the International Council for the Exploration of the Sea (ICES) and the International Commission for the North West Atlantic Fisheries (ICNAF) at their Sampling Meeting held in 1965 recommended that the length dimension to be measured for all species (except tunas and salmonids), for which length composition data are reported to the two commissions should be total length. This was defined as the maximum length as measured by bringing the longest lobe of the caudal fin into the mid-line of the fish (maximum total length). This standard covers most of the North Atlantic fisheries. This standard has since been accepted by most of the ICES member countries for most of the species, although it is still not universally in use. The 1968 meeting of the Regional Fisheries Advisory Commission for the Southwest Atlantic (CARPAS) approved the same standard for use in the Southwest Atlantic, and the General Fisheries Council for the Mediterranean (GFCM) (1963) adopted total length dimension for sardine. There thus seems to be already substantial agreement that fork length should be measured for tuna and mackerel, and maximum total length for nearly all other species.

Standard length is rarely used in fisheries studies, except by systematists. It is difficult to record accurately while working at speed and it has little to recommend its use in the field. Other standardized measurements in use by systematists are given in Appendix 1.

The important point to remember is to note whichever measurement you use and to state this in every publication, unless you are publishing in the statistical reports of a Commission which has an accepted standard. Failure to do so will inevitably result in confusion later. For example, one fisheries worker may measure fork length and a later

worker, studying the same species, total length. The latter may assume that the first worker also used total length, if he did not say so, and draw false conclusions about changes in growth rates and length-weight relationships.

Whichever length measurement is chosen the metric system is used for recording it.

3.1.2 Methods of measuring

Measurements are made with special measuring boards, tapes and calipers and they are usually, but not always, taken along straight lines. Overall length measurements are usually made with the fish lying on its right side, snout to the left, on a measuring board consisting essentially of a wooden or metal base carrying a centre scale and having a headpiece (nose block) against which the snout is gently pressed. The mouth is closed, the fish body and tail are straightened along the mid-line and the reading taken from the scale. The fish should be measured while it is fresh and wet, that is, as near to the relaxed live condition as possible; fish will shrink rapidly on drying. Normally, when the fish are measured on fishing craft or in markets at the time of unloading, this problem will not arise, but if samples are taken away for later observation, a means of conversion of measurements to fresh, wet condition may have to be employed. Fish in rigor mortis (stiffness after death) should be flexed gently before they are measured. In certain circumstances, for example, during tagging experiments, fish may be measured alive. Then it may be necessary to use narcotics to relax the fish during handling. A solution of Sandoz MS 222 is widely used for this purpose.

Rays and other dorso-ventrally flattened fish may be measured while lying straight on their ventral surfaces. Disc width rather than overall length is sometimes used as linear dimension of rays. Large, fat fish present difficulties. Their lengths may be measured with calipers or from point to point along the body surface with a tape.

Commonly, measuring is done by observers working in pairs, one of whom places the fish on the board and reads the length; the other records the measurements called out by the first. A common source of error is indistinct calling by the measurer, causing the recorder to write down the wrong length. Usually fish are measured under adverse working conditions, either in fish markets or at sea, where there is frequently a lot of background noise. So, the first rule of measuring is call out the length loudly and distinctly.

Various techniques have been developed to allow one man to measure fish on his own. The most practical of these are the one-man measuring board and the use of a portable tape recorder. The one-man board is described in Appendix 2. It has superseded similar devices where lengths were recorded by pricking holes in strips of celluloid or aluminium foil fixed to the board. The use of a reliable portable tape recorder can be extremely useful at times but transcribing the information later can be time-consuming, and unless it offers any special advantage it is rarely either more efficient or simpler to use than the one-man board.

A measuring board consists essentially of a flat platform which has a measuring scale on it and on which the fish is laid. At the zero end of the scale there is a head-piece or stop, against which the head of the fish is gently pushed. It usually has a handle to make it easy to carry. It must be both strongly constructed and retain its accuracy after several years of use in adverse conditions (soaked in sea-water) and of being mishandled (dropped). The scale must be clearly marked and easy to read. If ink is used to mark the scale it must still be clearly visible after at least one year, preferably longer. The scale must correspond to the measurements being recorded. It is impossible to measure fish to the nearest centimetre below on a board marked 2 cm intervals. If the scale has too many divisions either mistakes will be made or time wasted trying to record to the nearest division.

For fish measured in centimetre units, a board 1 m long is usually sufficient, although it may be useful to have an extension piece 30 cm long, which can be clipped or hinged on, if large fish regularly occur in the samples. For fish measured in half centimetre units a board 50 cm long is usually sufficient. Do not use a board that is more than 10 cm larger than the largest fish regularly measured.

3.1.3 Measuring damaged and processed fish

Suppose that total length is the basic dimension chosen. If an occasional fish in a sample has its caudal fin damaged, it should not be discarded but its total length should be estimated by comparison with another fish of about the same size. This will avoid possible bias arising if damaged fish tend to be either larger or smaller than the average.

If whole samples or large proportions of them are damaged or processed, for example, if the heads have been removed or the fish have been dried, another convenient dimension must be measured. The Peruvian anchoveta are a typical example of this problem; the largest fish have the least damage; the smallest fish are often so badly damaged that it is impossible to measure their total lengths. Head lengths are measured instead. A method of arriving directly at total length from the measurement of another dimension is possible by the use of a specially constructed measuring board described in Appendix 3.

If some other dimension, such as head length, is measured for all fish then it is not essential to convert these measurements to total length. More often these measurements have to be combined with others of total length (as for the Peruvian anchoveta) and a conversion key must be constructed so that the total lengths of fish whose other measurements, the head for example, have been recorded can be combined with others whose total lengths have been noted. Conversion keys must be applied only to the stock for which they were determined and should be checked periodically to see whether the key has changed. If it has changed the key must be recalculated unless some additional factors are found which allow the original to be used. As an example of possible change, the length of the head of a fast-growing fish forms a larger proportion of its total length than that of a slow-growing fish of the same size. The growth-rate is likely to increase as a stock is exploited and the abundance of the fish reduced. The original conversion key produced for the unexploited stock becomes invalid as the stock is exploited.

3.2 The Measurement of Shellfish

3.2.1 Molluscs

Bivalves (Fig. 3.1)

(i) Length of shell. The greatest measurement is in an anteroposterior direction; this is usually approximately parallel with the axis of the hinge.

(ii) Width of the shell. The greatest measurement is in a dorsoventral direction; this is usually approximately at right angles to the axis of the hinge and approximately at right angles to the length measurement.

(iii) Depth of shell. The greatest measurement is at right angles to the plane of the above two measurements.

The measurements are made with either calipers or measuring boards. (Loosanoff, V.L. and Nomejko, C.A., 1949).

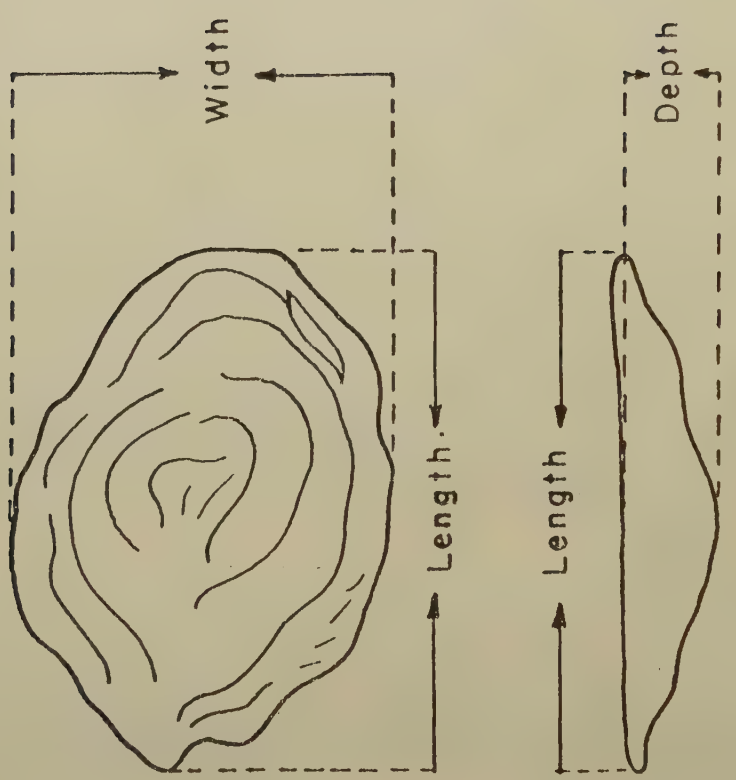


Fig. 3.1 Measurements of shellfish

Gastropods

The standard measurement is the maximum measurement from the tip of the whorl to the tip of the shell. (Warren, P.J., 1958).

3.2.2 Crustacea

Lobsters, crawfish, shrimps, prawns. The standard measurement is the minimum length of the carapace from the inside of the eye socket to the posterior margin of the carapace. In some cases (lobsters) the measurement is parallel to the mid-line and in others (some shrimps) it is from the eye socket to the centre of the dorsal margin of the carapace. (Cole H.A. and Mistakidis, M.N., 1953).

Crabs. The standard measurement is the maximum distance across the width of the carapace, including the spines if present, at right angles to the medium line.

All measurements are made with calipers.

3.3 Form for Recording Measurements

An example of the type of form used for recording measurement of many specimens of the same species is shown in Appendix 4. The main feature of this form is that only the units (0-9) are marked. The technique of using it is to establish the size range in the sample by selecting the largest and smallest fish visible. Say these fish are 55 cm and 25 cm long. A '1' is then placed before the first zero to make it read '10' and subsequent zeros made to read 20, 30, 40, 50 and 60. It should then be possible to record all fish within the sample. If a fish smaller than 10 cm or longer than 69 cm is found its length has to be noted separately. A form with 0.5 cm interval would be needed for recording fish to this length interval.

Each fish measured should be recorded in a square against the appropriate length, building up a series of windows of blocks in each square thus each representing five fish. This is a foolproof system, quick and easy to use and less liable to error than other methods, e.g. 𝍸 of ⁘; with either of these methods it is possible to make simple mistakes either by inserting an extra vertical stroke or missing a single dot when totalling up the measurements.

The other side of the form is used to record details of the vessel, fishing gear, date and place of landing, area fished and quantity of all categories of the species landed.

3.4 Units of Measurement and Grouping of Data

The metric system should be used for all scientific measurements relating to the assessment of fish stocks. Choice of the class interval for recording length measurements is a matter of judgement but it is usually made in 1 cm units for species which grow larger than 30 cm and in 0.5 cm units for species which do not reach 30 cm. For very small species and for larval fish it may be necessary to work to 1 mm intervals but this is exceptional.

The method of reading length to the unit below has been agreed by the ICES/ICNAF Sampling Meeting 1965, the FAO Working Party on Tuna Length Measurements and Tabulation 1967, CARPAS 1968, the West African sardinella investigations 1967, and the GFCM sardine workers 1963. According to this method all lengths between 26.0 and 26.99 cm should, when recording in centimetres, be noted as 26 cm. Similarly when measuring in 0.5 cm units fish between 26.0 and 26.49 cm would be recorded as 26 cm and fish between 26.5 cm and 26.99 cm as 26.5 cm. This method has now become fairly universally agreed, at least in the Atlantic regions. It is far more satisfactory than measuring to the nearest unit, in which case 26 cm would mean all fish between 25.50 cm and 26.49 cm when measuring to the nearest centimetre and all fish

between 25.75 cm and 26.24 cm when measuring to the nearest 0.5 cm.

It is often advantageous to combine length data into large groupings. The appropriate grouping interval for a species depends on the purpose for which the data are to be used and on the acceptable limits of accuracy of the estimates derived from them. Too fine grouping greatly increases the space needed in publication, the work of tabulating the data and the difficulties of calculations, without adding significantly to the accuracy of the information provided. A grouping such that the available length data fall into a range of about 20 units is sufficiently fine for most purposes.

In order to ensure that data can be pooled even when practices differ, it is suggested that the basic system of grouping agreed upon by the FAO Working Party on Tuna Length Measurements and Tabulation is adopted for general use. In this system, regardless of which unit of length interval is used, the groups always start at zero, and the only intervals used are 0.5, 1, 2 and 4 and 8 cm. Thus, the data given in the smaller units can always be combined into the larger groups if desirable for purposes of pooling with data given in other units, as is demonstrated in the following scheme:

Length Intervals		Grouped into 0.5 cm		1.0 cm		2.0 cm		4.0 cm		8.0 cm	
		m*	*fr**	m	*fr*	m	*fr*	m	*fr*	m	*fr*
Greater than or equal to	but less than										
0.0	0.5	0.25	2								
				0.5	5						
0.5	1.0	0.75	3								
						1	21				
1.0	1.5	1.25	6								
				1.5	16						
1.5	2.0	1.75	10								
								2	96		
2.0	2.5	2.25	16								
				2.5	34						
2.5	3.0	2.75	18								
						3	75				
3.0	3.5	3.25	20								
				3.5	41						
3.5	4.0	3.75	21								
										4	373
4.0	4.5	4.25	19								
				4.5	46						
4.5	5.0	4.75	27								
						5	122				
5.0	5.5	5.25	34								
				5.5	76						
5.5	6.0	5.75	42								
								6	277		
6.0	6.5	6.25	48								
				6.5	92						
6.5	7.0	6.75	44								
						7	155				
7.0	7.5	7.25	32								
				7.5	63						
7.5	8.0	7.75	31								

Explanation overleaf

*m = mid-point of the length unit; fr = imaginary size distribution used as example

This scheme also shows the figures of the mid-points of each grouping. These mid-points have to be taken into account in calculations such as that of average length, etc. It should be made clear in the tabulation of size distributions whether the sizes given refer to the unit below or to the mid-point of the grouping. A convenient way, which leaves no ambiguity, is shown in the following example:

26 - means greater than or equal to 26 but less than 27, i.e. incorporating all intervals from 26.00 - 26.99, etc.

This scheme demonstrates the advantage of reading to the centimetre below compared with reading to the nearest centimetre. With the latter method 26 cm would mean all fish of lengths 25.50 cm to 26.49 cm.

One practical point; when calculating mean lengths of fish measured to the nearest centimetre below it is necessary to add 0.5 cm to the mean length calculated. The reason for this is that some fish will be only 26.0 but others will be as long as 26.9 cm. The mid-point will be 26.5 cm.

3.5 Reporting of Length-Composition Data

Reporting of age- and length- composition data for inclusion in Biological Sampling Yearbooks and in general for assessment purposes should be done in a standardized form which includes all essential information. Some general criteria have been developed and are in use in other international organizations.

There are two sources of length-composition data; those obtained from:

(a) comprehensive market sampling programmes, and
(b) occasional sampling of commercial landings and research vessel catches.

For assessment purposes the first of these is usually most important, but data from both of these sources are valuable and should be reported, clearly specifying the category to which the data belong. If possible, data from source (a) should be expressed as the length-composition of the total landings of all that species for the particular gear, area and time interval. They should also be accompanied by the following additional information:

i) number and size category of vessels sampled;
ii) number or weight of fish measured;
iii) total number or weight of fish landed by the fishery for the particular gear, area and time period.

An example of the reporting form used by ICES is shown in Appendix 5.

The data from source (b) should be submitted as per mille frequency distributions, and should be accompanied by the following additional information:

i) source (e.g. research vessel, commercial vessel, etc.);
ii) gear used (including mesh or hook size);
iii) number or weight of fish measured;
iv) number or weight of fish caught or landed.

3.6 Weighing

Weights are as good as length measurements but they are not used routinely because they are time-consuming to collect and liable to large inaccuracies. However, it is essential to establish length-weight relationships for all species because at some stage in stock assess-

ments lengths of fish have to be converted to weights of fish. It is useful to have seasonal length-weight relationships for both whole and gutted fish; this is particularly useful for whole fish whose weight may be much greater during the spawning season than during the non-spawning season.

To convert 'landings' to 'nominal catch' it is essential to establish relationships between weights of fish as landed and whole weight for all ways in which the fish is landed, such as gutted, headed, filleted.

Weights of various parts of the fish may be required for biological studies; stomachs for the determination of food eaten, gonads for the estimation of egg numbers and livers for liver-condition assessment.

The only reliable transportable instruments are steelyards and spring balances. The latter are sensitive to temperature changes and many other factors, but small pocket-size spring balances in various ranges (e.g. 0.1 kg and 0-10 kg) are useful for rough measurements and should be carried on all field trips. Simple transportable laboratory balances are also useful but the weights with which they are used make them slow in use. Shop balances can also be used in fish markets, if a stable base can be provided and care is taken of them in transport. Excess water must continually be removed from the pans of these balances or the weights will become increasingly inaccurate during a recording period.

It is usually so difficult to weigh fish at sea that samples are often preserved by either deep freezing or placing in formalin for later weighing ashore. To avoid losses in a deep freeze fish must be placed in tightly sealed polythene bags. For fish preserved in formalin fresh-preserved weight conversion factors must be established.

3.7 References

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Loosanoff, V.L. and C.A. Nomejko, 1949. Growth of oysters, O. virginica during different months. Biol.Bull.Mar.Biol.Lab., Woods Hole, 97(1):82-94

Warren, P.J., 1958. Advice for rapid single-handed measurement of shellfish. J.Cons.Perm. Int.Explor.Mer, 23(3):440-2

Appendix 3.1

Definition of Linear Measurements

Overall lengths may be measured from the snout (U, the position of the maxillary symphysis) or from tip of the lower jaw (L, the mandibular symphysis). Measurements from L are taken with the mouth closed. If the lower jaw projects much beyond the upper jaw, measurement from S may necessitate provision of a special "stepped" nose piece on the measuring board.

There are three main overall length measures in common use. These are roughly illustrated in Figure 1. Standard length, the standard dimension of taxonomy, is properly measured from U to the tip of the hypural bone (urostyle). In practice it may be measured to some external feature more or less corresponding with the latter point; this would vary from one species to another but examples are the last scale, or point of silvering, to edge of skin pigment (determined by scraping away the posterior scales), to tip of fleshy peduncle or to the keel. Fork length is measured from U or L to the cartilaginous tip of the shortest, or median, caudal fin ray. It may be difficult to measure if the tail is split. Total length is measured from U or L to the tips of the longest caudal fin rays, in several possible ways. Measurement may be taken to the tip of the dorsal lobe, of the ventral lobe, or of the longer of the two, or some average of them both (such as to the midpoint of a line joining the two tips or to the point where such a line crosses the median longitudinal axis).

The tail fin may be in the extended position to give normal (total)length or the tips of one or both caudal lobes may be drawn to the longitudinal axis extreme (total) length. Sometimes total length measurements are made with the caudal lobes partially drawn together so that their outer edges are parallel to each other and to the axis. It is therefore clear that precise instructions must be given as to the dimension to be measured and the mode of measuring. In particular, if a normal length is the chosen dimension, it is necessary to standardize the procedure of laying the fish on the board. A common method is to place the head of the fish against the nose piece with the right hand, hold the fish in position with the left hand, and use the right hand to straighten the body of the fish and extend its tail with a single stroking movement.

There follow useful sets of notations and definitions for positions and linear measurement, which are applicable to many types of fish; they are illustrated with reference to a scombroid.

Positions are defined as on the left side of the fish unless stated to the contrary. When side-to-side comparisons are being made, or if necessary for other reasons, distinguish by prefixing "r" or "g" (right or greater) to the notation (or term). This rule may be especially applicable to the dimensions Ph and Vh.

Lower-case letters are used by themselves in the notation where the dimension is not defined with respect to two fixed points, e.g., q, b, g. Otherwise d stands for "diameter", h for "depth", and g for "greatest".

Overall length measurements are always made between perpendiculars along the median longitudinal body axis from L or U with mouth closed. Measurement is understood to be from L unless otherwise specified, thus, e.g., UX Upper (or "maxillary") dorsal extreme length.

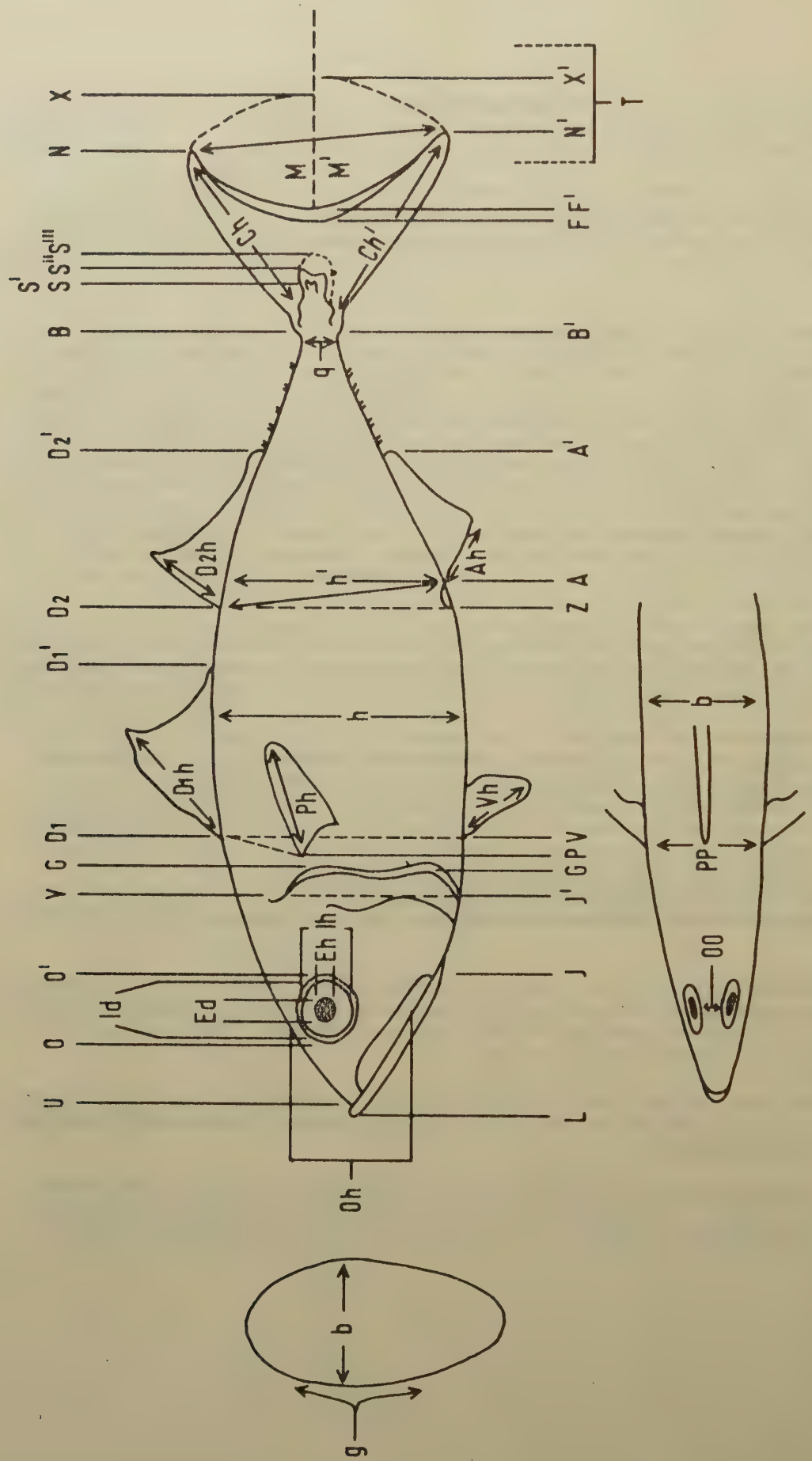


Fig. 1 Body measurements of fish

Longitudinal measurements other than overall length are also often made between perpendiculars, using a measuring board with, for example, a sliding cursor. When they are made radially from point U, using calipers as is recommended, the symbol for the dimension should be in parentheses, and the name followed by the qualifying term "direct". Point-to-point measurements are sometimes made on big fish, e.g., tunas, by tapes. They would be indicated by the word "surface"; they are not generally recommended. The term "radial" is not recommended to be applied to point-to-point measurements as it invites confusion with fin-ray counts.

All measurements listed from LX to LM and also their "upper" equivalents are grouped under the general name "total length", LT. LM has also been called "bilobular length" and "total auxiliary length". It is rather difficult to measure.

The word "extreme" is used in LX, LX' and LX'' instead of "maximum" to avoid confusion with the asymptotic size referred to the growth studies. "Greatest" is a possible alternative to "extreme" but invites confusion with "greater"for which a suitable alternative cannot be found.

LF and LF' have also been called "median length" or "midcaudal length". The term "standard length" has on occasion been applied to the distance LB as well as to the LS series; this usage is not recommended. It is not known that the ventral body length, LB', has ever been used in practise.

"Depth" is used in terms from Oh to q instead of the alternative "height" to avoid possible confusion with fin heights as measured by length of rays. The ambiguous term "width" is not recommended. Again "width" is not recommended as an alternative to "breadth" in terms for PP and b but "thickness" would be suitable.

Pectoral and ventral fins, Ph and Vh, are usually measured in their folded positions opposed to body side (to keep rays straight) from foremost visible point of insertion to the distal tip of the membranous edge.

In measurements of eyes the limits of Id, Ih and Ig are the boundary of the iris with the black tissue. Ig and Eg are not necessarily equivalent to either Id or Ih, Ed or Eh respectively.

The method of measuring g, in particular the permissible degree of constriction of the belly, remains to be defined precisely. Other girth measurements might be more consistent and perhaps related to conditions relevant to selectivity problems, e.g., if taken level with Y or D1. An appropriate notation could be gY, gD1, etc.

Spread caudal distance NN' has been used for tunas.

In various types of fishes certain of the dimensions listed may be virtually indistinguishable. Thus in the mackerel Rastrelliger LM = LM', LS = LS', UJ = UO', UY = UJ', and so on.

Definitions of position

U	Maxillary symphysis
L	Mandibular symphysis
OO	Anterior edge of orbit
O'	Posterior edge of orbit
J	Posterior edge of mandible (buccal commissure)
Y	Gill-cover notch

C Posterior bony edge of operculum

C' Posterior membranous edge of gill cover

P Anterior point of insertion of first pectoral fin ray

D1 Insertion of anterior dorsal (intersection of anterior margin of first dorsal spine, fin held erect with the contour of the back)

D1' Position of last ray of anterior dorsal

D2 Insertion of first ray of posterior dorsal

D2' Position of last ray of posterior dorsal

Z Anterior edge of cloaca

A Insertion of first anal fin ray

A' Position of last anal fin ray

B Insertion of dorsal lobe of caudal fin

S Posterior tip of urostyle (forward protuberance of hypural blade)

S' Posterior edge of fleshy peduncle or of pigmented zone

S'' Point of upper caudal keel

S''' Posterior limit of silvering (either last scale of the lateral line or the posterior limit zone of the scale covered by the peduncle)

F Cartilaginous tip of shortest (median) caudal ray

F' Membranous edge of caudal fin at fork

N Distal tip of the longest dorsal caudal fin ray, lobe normally extended

N' Distal tip of the longest ventral caudal fin ray, lobe normally extended

M Point where line NN' intersects median longitudinal axis

M' Midpoint of line NN'

X Distal tip of longest dorsal caudal fin ray, with the lobe brought to the median longitudinal axis

X' Distal tip of longest ventral caudal fin ray, with the lobe brought to the median longitudinal axis

Overall length measurements

LT and UT total length (any extreme or normal length)

LX Dorsal extreme length

LX' Ventral extreme length

LX'' Greater extreme length (LX or LX', whichever is greater)

LN Dorsal normal length

LN' Ventral normal length

LN'' Greater normal length (LN or LN', whichever is greater)

LM Median normal length

LM' Mean normal length

LF Midcaudal length

LF' Fork length

LS Standard length to urostyle (or to some external feature corresponding with it, see commentary)

LS' Standard length to peduncle (or to pigment under scales)

LS'' Standard length to keel

LS''' Standard length to silvering

LB (Dorsal) Body length

Other longitudinal measurements

UJ Maxillary sheath length

LJ' Mandibular length

UO Snout length

UY Upper head length

LG Opercular head length

Lg Greatest head length

OO' Orbital diameter

Id Longitudinal iris diameter (cf. Ih and Ig)

Ed Longitudinal pupil diameter (cf. Eh and Eg)

O'Y Postorbital distance

UD1 Preanterior dorsal distance

UP Prepectoral distance

UV Preventral distance

UD2 Preposterior dorsal distance

D1D1' Anterior dorsal fin base length

D2D2' Posterior dorsal fin base length

UA Preanal distance

AA' Anal fin base length

Vertical measurements (perpendicular unless otherwise stated)

Oh Orbital depth (from orbital crest to lower edge of maxillary, passing over middle of pupil)

Ih Perpendicular iris diameter

Eh Perpendicular pupil diameter

YJ' Head depth

D1P Back depth (oblique)

D1V Anterior dorsal depth (or dorsoventral depth)

h Greatest depth

D2Z Posterior dorsal depth

D2A Dorsoanal depth (slightly oblique)

h' Perpendicular anal depth

q (Least) peduncle depth

Lateral measurements

PP	Pectoral breadth
b	Greatest breadth
OO	Interorbital distance (at level of pupil centres)

Other measurements

D1h	Anterior dorsal height (distance from insertion to tip of longest spine)
D2h	Posterior dorsal height (distance from insertion to tip of longest spine)
Ph	Pectoral fin length
Vh	Ventral fin length
Ah	Anal fin height
Ch	Dorsal caudal fin length
Ch'	Ventral caudal fin length
Ch''	Greater caudal fin length
Ig	Greatest iris diameter
Eg	Greatest pupil diameter
g	Greatest girth
VV	Length of interventral flap
NN'	Spread caudal distance

Skeletal dimensions

Ax	Axial length (anterior face of vertebra 1 to tip of urostyle)
Sk	Skull length (maxillary symphysis to posterior occipital boundary)
An	Anatomical length (= Ax + Sk)

Appendix 3.2

INDO-PACIFIC FISHERIES COUNCIL

Occasional Paper 60/3

"ONE-MAN" MEASURING BOARD

by

T. Williams, Fisheries Laboratory, Lowestoft

During the FAO International Training Centre on the Methodology and Techniques of Research on Mackerel held at Bangkok in 1958, the possibility of producing a "one-man" measuring board was discussed. It was decided that the board needed to be simple to use, inexpensive to produce, and one that would enable a research worker to measure and record, single-handed, large numbers of fish under field conditions.

The Fisheries Laboratory at Lowestoft, England, made and tested a board according to the principles laid down at the Training Centre and found that it fulfilled these requirements.

Figure 1 is a drawing of the board showing the scale marked in centimetre units, and a line drawn down its median axis to help keep fish straight during measuring. The scale is drawn using an ordinary pen, and printers' ink Grade HJ. 150/A, on a white, matt surfaced, plastic material, which is attached to the wooden board with an impact adhesive ("Evostick" was the adhesive used).

The plastic surface is 0.02 inch thick and the material has the trade name "Astrafoil". It is supplied with one side polished and one side matt, and it is necessary to roughen the polished side before attaching it to the wooden board.

Parana Pine, a knotless wood which is easily obtainable locally in England, was used to make the measuring boards, but a hard wood would be equally suitable. It was not found necessary to treat the wood of the boards that were used during the trials, but it may be found desirable to varnish it to prevent warping, should the boards be subject to continuous soaking, followed by storage under conditions of high temperature.

When measuring fish, each one is laid on the board with the head touching the upright headpiece. The fish is straightened so that it is parallel with the median line, and the length is recorded by a pencil mark in the centimetre space within which lies the extreme end of the tail or other point on the fish from which the measurement is to be taken.

The length distribution of the sample is built up by recording the lengths of the fish in this way. The marks, each of which represents a fish, are usually arranged in blocks of five, either or .

Two or more samples may be measured without the board being cleaned, provided there is sufficient space for recording, and the samples are clearly separated.

Figure 2 shows a series of lengths recorded on the board and a fish being measured. Sample 1 has been completed, and is separated from Sample 2 by a line drawn by the measurer.

The method of measuring described above results in the fish being measured to the centimetre below its actual length, e.g., a fish of 25.8 cm is recorded as 25 cm. If it is required to measure a fish to the nearest centimetre, e.g., a fish of 25.8 cm being recorded as 26 cm, then this can easily be achieved by screwing a 5 mm block to the upright headpiece, as illustrated in Figure 1.

A soft pencil is used for recording on the board and the marks can be removed with an ordinary pencil eraser. If, after a period of use, the board becomes difficult to clean thoroughly, xylol applied with a soft cloth and rubbed hard will remove all the pencil marks. This should not be done too frequently, as xylol removes a little of the ink each time it is applied.

"Astrafoil" supplied by D.E.P. Ltd., Frith Park, Walton-on-the-Gill, Tolworth, Surrey.

Printers Ink, Grade HJ. 150/A supplied by Hellerman Ltd., Crawley, Sussex.

Note by S.J. Holt (FAO)

Since this paper was written the measuring board described has been used with success by Mr. G. Tront aboard the FAIRTRY, a large British factory trawler. At FAO a soaking test has shown that "bubbles" between the plastic surface and the wooden base removed themselves when the board is immersed for a few hours; thus wetting improves the board, at least in this respect.

FAO has distributed 20 models of the board among IPFC member countries for field tests, the results of which it is hoped will be reported to the Council.

Author's Note

Later versions of the board have been made with resin-bonded marine plywood approximately 18 mm thick; this material is less liable to warp and has a longer life under field conditions.

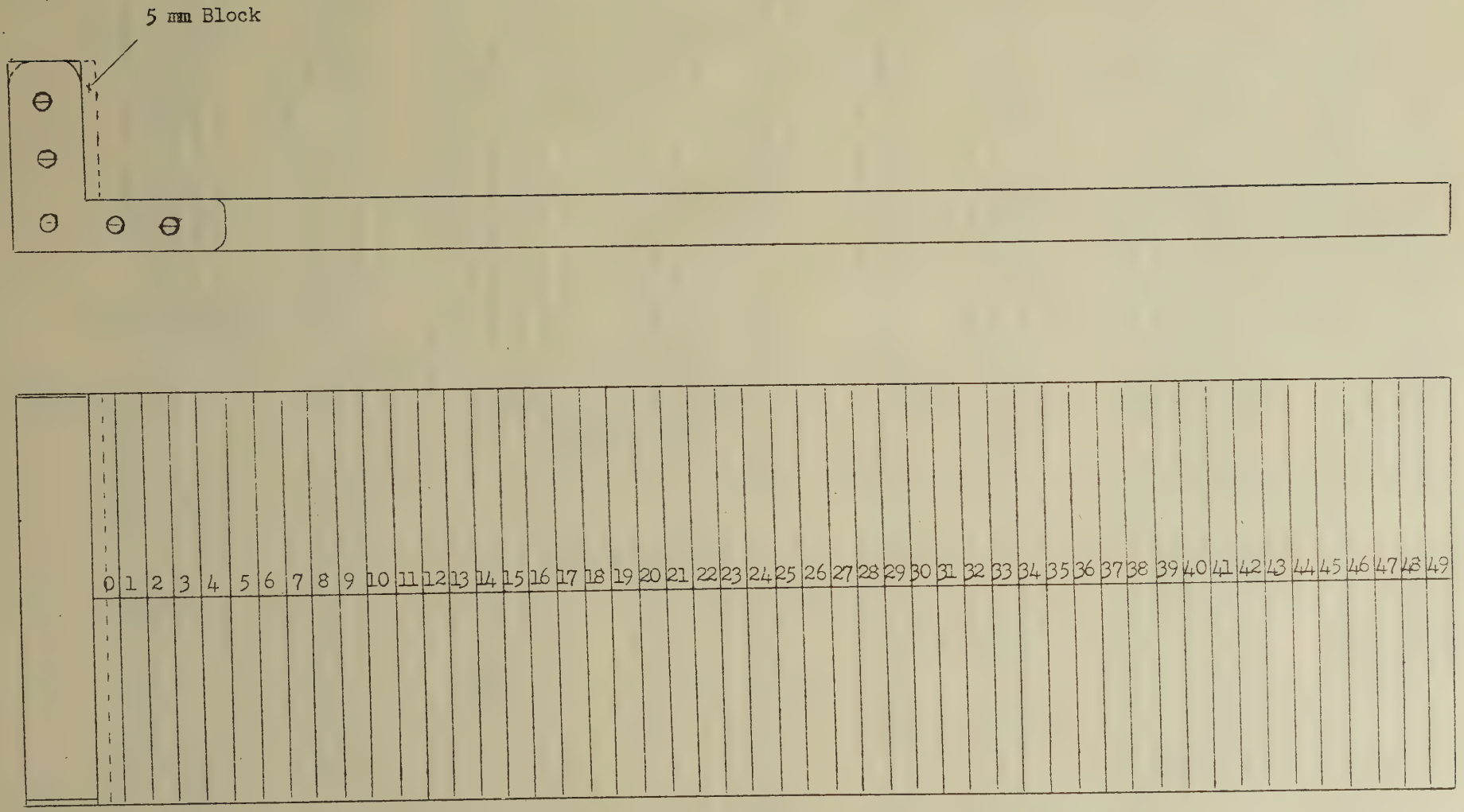

5 mm Block
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49

Fig. 1

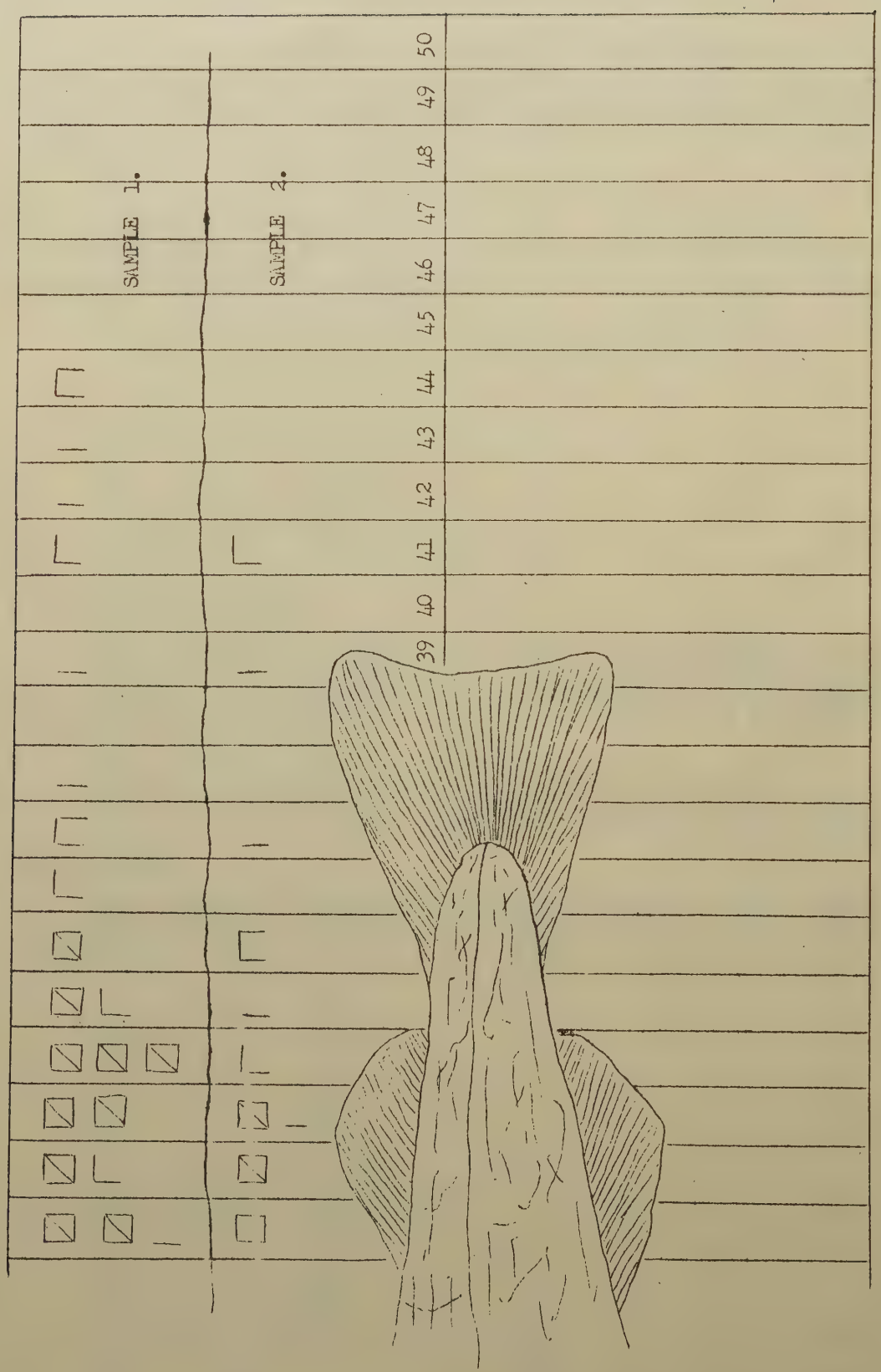


Fig. 4

Appendix 3.3

"A Method of Measuring Headless Fish"
(Reprinted from J.Cons.Perm. Int.Explor.Mer, 31 (2): 279-83)

A common problem for the fishery scientist is to measure some attribute of a population. The study of catches of fish by commercial vessels for species, size, age, maturity or other characteristics often involves the organization of some sampling system. Of the many observations that can be made, the one that is most frequently chosen is that of total length, which can be quickly and accurately measured. Total length is usually closely related to many of the other factors, e.g., weight, age, maturity, etc., so that any of the latter may often be most easily determined from the length data plus a small key sample relating length with the factor concerned.

The difficulties usually encountered when trying to obtain the length composition of a commercial catch are those of planning and organization, e.g., deciding the size of the sample to be measured, the frequency of sampling, and the stage at which the measuring should be done, e.g., whether at sea, immediately after landing, or later - after sorting and selling.

If it is decided to measure the fish ashore, an additional complication sometimes occurs, i.e.,the heads of some of the fish may be removed at sea before stowage, and part of the catch landed headless. The problem then is the difficulty of finding out what was the total length of all the fish.

This problem has recently been encountered in South Africa, where a team from the Lowestoft Laboratory is carrying out a survey of the stocks of hake (Merluccius capensis) in the area. It was found, however, that there are linear relationships between the total length (Lt) of the fish and the measurements Lp (the length from pectoral fin to end of tail) or La (the length from anus to end of tail). These relationships were therefore calculated as follows: a sample of over two hundred fish, covering the whole of the length range, was taken, and on each fish measurements were made of Lt, Lp and La. Mean values of Lp and La were plotted against total length to give two straight line relationships, (Lp=0.728 Lt+0.788; La=0.568 Lt+2.293) which are shown in Figure 1.

These relationships were then read from the graph (Figure 1) and used to construct a specially calibrated measuring board that immediately converts Lp or La into total length. For the Lp calibration the board is graduated in units of 7.28 mm, each unit being equivalent to 1 cm of total length; thus if Lp measures 35 cm this is equivalent to a total length of 47 cm and this is read off directly from the board (Figure 2). Other examples are given in Figure 3. The factor for La is 0.568, and for this conversion the board would be graduated in units of 5.68 mm. One board could be graduated to measure both Lp and La (Figure 4).

In this way the total lengths of large numbers of headless fish are measured quickly and easily, and a size composition of the catch by total length is directly recorded, without the need of any further conversion. It is obvious that the relationship Lp or La to Lt will vary between species, or possibly between similar species from different areas, and new values of the function of Lp and La to Lt should be established when any new stock is sampled.

When measuring headless fish a board without a headstock is necessary because the base of the pectoral fin is placed against the end of the board, the fin being held at right angles to the fish. However, a normal board with headstock can be used in the usual way for measuring total length of whole fish, whilst the end away from the headstock is calibrated to measure total length of headless fish by means of either Lp or La (Figure 5).

The most suitable type of measuring board for this work is the "one-man board" developed at the Fisheries Laboratory, Lowestoft; this board is surfaced with a matt white plastic (Astrafoil), is cheap to produce, quickly and easily calibrated, and has proved most satisfactory in use. It is fully described in the FAO Indo-Pacific Council Paper No. 60/3. The measuring boards used in South Africa were made of 1.9 cm resin-bonded marine plywood, which has proved less likely to warp than other types of wood.

The Lowestoft board can be used in the ordinary way with two men, one recording and one measuring, but its main advantage is that it can be used as a one-man board, the measurements being recorded directly on to the board by the measurer. A soft pencil is used for recording and will write on the plastic-surfaced board through water or fish slime. A pencil mark is made in the centimetre space within which the end of the tail lies, and the marks are usually built up in blocks of five as shown in Figure 6. When a sample has been complete it is a simple matter to transfer the numbers of fish, marked on the board at each length, to a log book. The board is then cleaned with an ordinary india rubber and the procedure repeated for subsequent samples.

This method is similar to the one described by Davenport and Harling (1965), but instead of transferring the recorded measurements from the plastic board to a log book, they used a new graduated plastic strip, pinned to the board, on each occasion.

Reference

Davenport, D. and W.R. Harling, Method of rapid measurement for large samples of fish
1965 J. Fish.Res.Bd Can., 22:1309-10

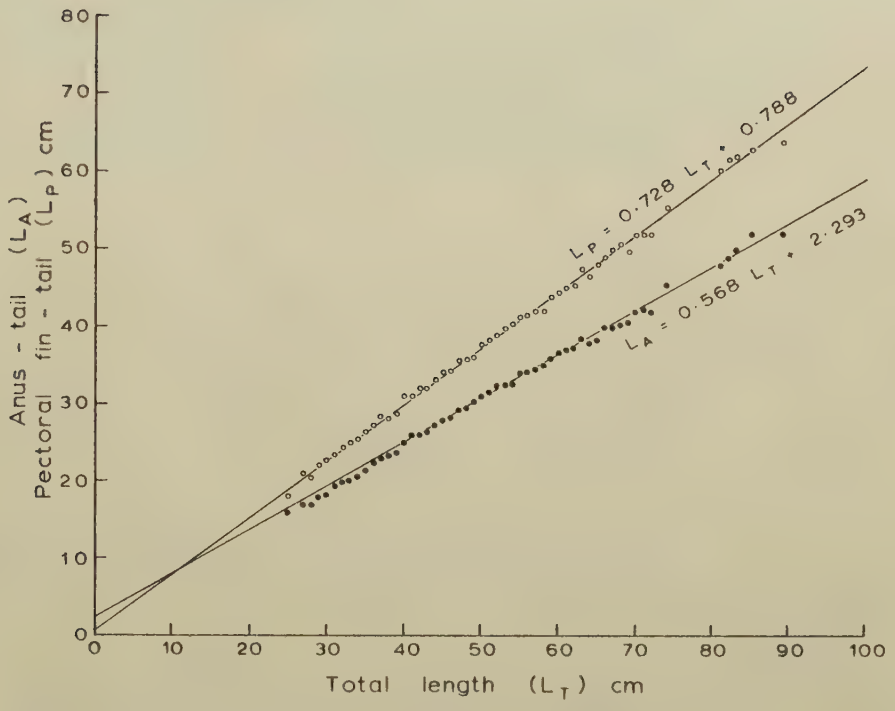


Figure 1. The relationships between L_T and L_P or L_A for South African hake. L_T = total length; L_P = length from pectoral fin to end of tail; L_A = length from anus to end of tail.

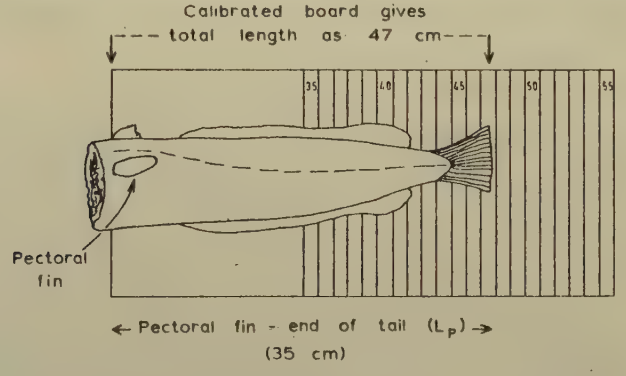


Figure 2. Measuring board graduated in units of 7·28 mm to give total length by measuring L_P.

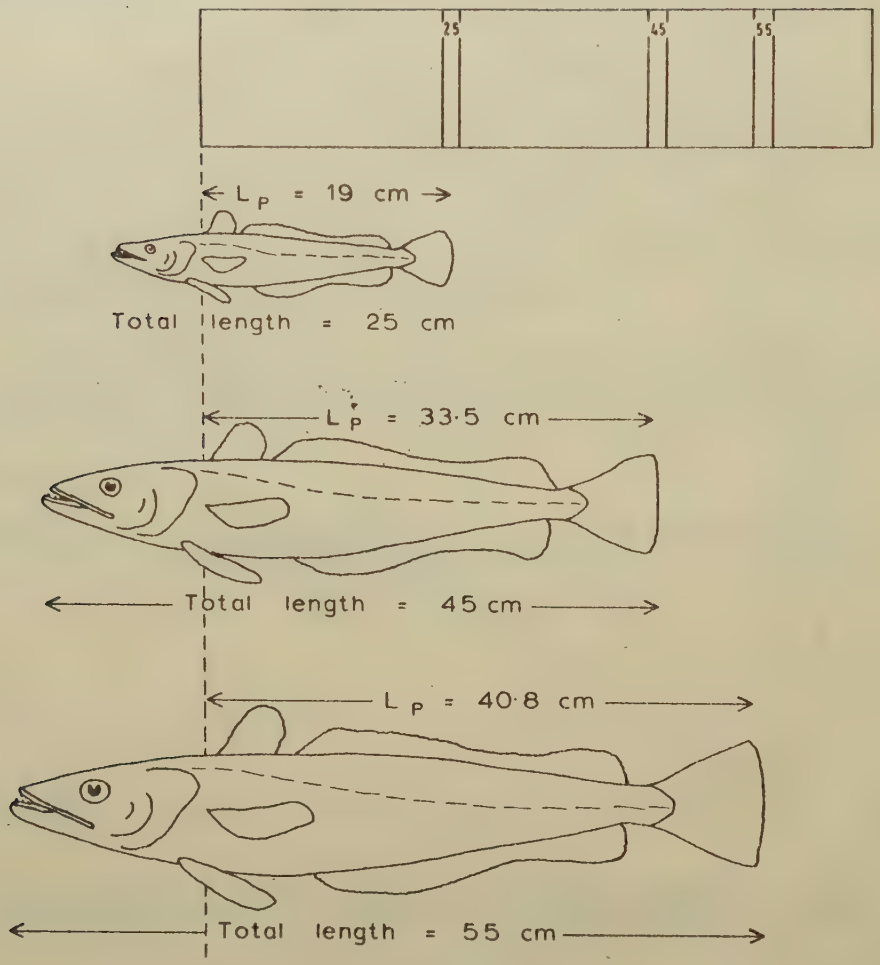


Figure 3. Three examples of L_P being directly recorded as total length.

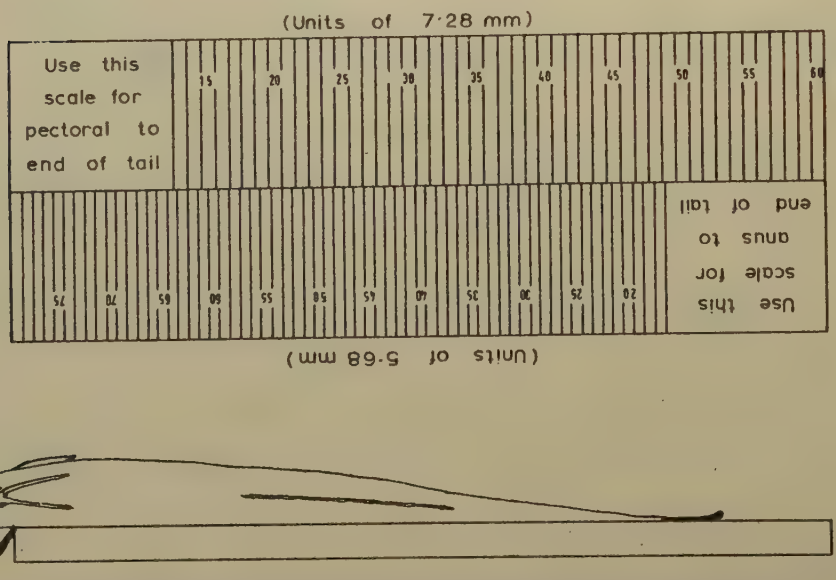

(Units of 7·28 mm)
Use this scale for pectoral to end of tail
15 20 25 30 35 40 45 50 55 60
Use this scale for anus to end of tail
20 25 30 35 40 45 50 55 60 65 70 75
(Units of 5·68 mm)

Figure 4. Board without headstock graduated to record total length from both L_P and L_A.

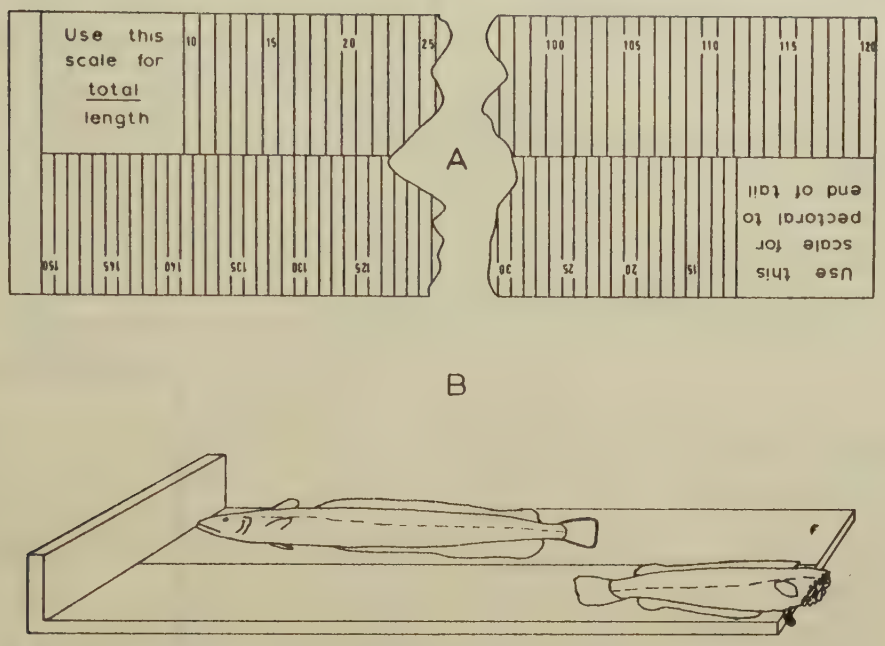


Figure 5. A. Measuring board graduated to measure both total length of whole fish and also total length (from L_P) of headless fish. B. Positions of the fish on the board.

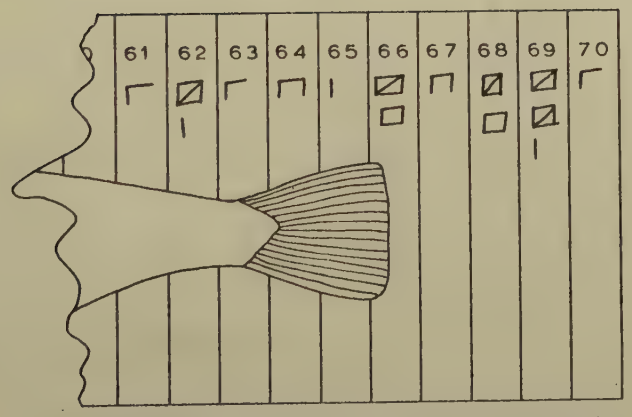


Figure 6. The method of recording on a one-man measuring board.

Appendix 3.4

		CODE
MARKET		
NAME OF FISH		
DATE		
NAME OF VESSEL	=	
PORT LETTERS AND NUMBERS		*
MOTIVE POWER		
GEAR		
REGION		
RECTANGLE		
FISHING GROUND	=	*
NUMBER OF CATEGORIES SORTED		

	CATEGORY	STONES	CODE
TOTAL CATCH OF EACH CATEGORY OF THIS FISH, WHETHER SAMPLED OR NOT			
CATEGORIES NOT SAMPLED			
			—1

REMARKS

FL 7 MEASURER.....

Example of the type of form used for recording measurements of many specimens of the same species

CODE	CATEGORY	VESSEL	
	Number of Stones Sampled:	DATE	FISH
	..... of		
	• All fish measured; non discarded • 1 measured; .....discarded	(•Delete as appropriate)	

| | | |

Appendix 3.5

Standard form used by ICES for reporting measurements of fish landings from regular market sampling programmes

Table 1. Netherlands. Number (in thousands) of North Sea Whiting of different sizes landed at Dutch ports in 1962 specified by three month periods

Length (cm)	Northern North Sea				Central North Sea				Southern North Sea				
	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total
20	1	12			3	9	3		5	42		4	1	43
21		6		2		11	9		21	2		8	22	28
22		11		9	5	20	46	1	25	112	6	28	49	175
23	2	23	7	20	19	53	49	1	66	41	3	52	119	191
24	6	40	19	42	28	87	89	4	122	176	46	92	210	484
25	29	99	32	73	58	165	205	18	208	237	109	145	260	698
26	114	160	60	93	75	217	362	36	446	484	186	256	366	1,181
27	253	227	102	168	79	242	459	47	690	721	375	328	427	1,779
28	506	309	139	185	54	213	486	60	827	1,101	603	396	396	2,428
29	864	343	139	185	42	233	533	62	813	895	723	377	498	2,493
30	1,011	314	170	230	42	191	479	35	870	1,033	734	550	402	2,741
31	965	262	182	285	42	191	479	35	747	634	601	368	328	1,931
32	883	258	177	251	23	166	425	46	660	409	421	317	263	1,410
33	730	188	124	249	18	87	326	38	469	343	393	258	194	1,188
34	456	152	85	220	8	70	216	42	336	131	278	256	127	792
35	354	117	57	199	3	55	164	25	247	176	203	183	80	642
36	217	69	36	154	3	31	111	24	169	89	141	133	50	413
37	148	55	29	171	4	8	118	13	143	30	79	84	50	263
38	77	35	12	129	2	7	71	10	90	13	59	52	27	151
39	76	29	11	103		7	34	5	46	10	47	35	18	110
40	39	9	15	84	1	10	6	10	27	4	28	30	10	72
41	28	13	3	42		6	13	3	24		17	9	5	31
42	17	10	4	39			10	1	11		7	12	5	24
43	8	3	4	17			3	2	5		5	6	2	13
44	10		7	17							1	3	1	5
45	4	1		9	1		1		2	2	1	2	3	8
46	5			6							5	1		6
47	3			4							1			1
48	2	1		2										
49	2					1		1						
50			1	2										
>50	1													
Total	6,815	2,746	1,415	2,806	468	1,889	4,229	434	7,070	6,727	5,072	3,589	3,913	19,301
				13,782										

Table 2. Netherlands. Number (in thousands) of North Sea Whiting of different year-classes landed at Dutch ports in 1961 and 1962 specified by three month periods

Year-class	Nothern North Sea					Central North Sea					Southern North Sea				
	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total	Jan.-March	Apr.-June	Jul.-Sept.	Oct.-Dec.	Total
1961															
1960	32	13	2	407	454	-	20	54	5	79	60	42	139	787	1,028
1959	421	1,728	161	2,125	4,435	34	909	1,562	167	2,732	2,527	1,071	3,084	2,616	10,798
1958	1,204	1,805	333	751	4,093	56	1,087	1,361	91	2,595	4,980	3,233	2,708	891	11,878
1957	779	231	66	84	1,160	3	103	497	23	626	337	343	72	-	802
1956	186	47	15	29	277	1	35	-	-	36	-	-	-	-	-
1955 1)	130	19	-	2	151	-	12	-	-	12	-	-	-	-	-
Total	2,752	3,843	577	3,398	10,570	94	2,226	3,474	286	6,080	7,960	5,289	6,903	4,294	24,506
1962															
1961	3	52	60	495	610	8	93	206	12	319	285	87	1,276	2,509	4,157
1960	964	783	421	1,146	3,314	97	541	472	96	1,206	577	980	606	462	2,625
1959	4,192	1,217	590	956	6,955	312	874	2,387	296	3,859	4,323	3,202	1,448	860	9,833
1958	1,254	605	312	158	2,329	49	141	1,118	72	1,380	1,542	803	213	63	2,621
1957	292	84	20	51	447	1	239	55	8	303	-	-	46	19	65
1956	94	5	7	-	106	1	1	-	-	2	-	-	-	-	-
1955 1)	16	-	5	-	21	-	-	-	-	-	-	-	-	-	-
Total	6,815	2,746	1,415	2,806	13,782	468	1,889	5,228	484	7,069	6,727	5,072	3,589	3,913	19,301

1) 1955 and older

4. AGE DETERMINATIONS AND AGE COMPOSITIONS

The exact age determination of fish is one of the most important elements in the study of their population dynamics. It forms the basis for calculations leading to a knowledge of the growth, mortality, recruitment and other fundamental parameters of their populations.

Many species of fish can be aged from the discontinuities which occur in their skeletal structures. These discontinuities may result from either changes (such as temperature) in the environment which the fish inhabits, or changes (such as spawning) in the physiology of the fish. However, many fish live in such a uniform environment that discontinuities do not form in their skeletal structures and ageing of these fish has to be done indirectly; it may often be impossible. In the first part of this section the methods used for fish with skeletal discontinuities will be described and in the second part the methods available for fish without them. The third part deals with growth rates and the fourth part describes methods of obtaining age compositions from age-length keys.

4.1 Age Determination from Skeletal Structures

Almost every skeletal structure has been used for age determination of fish. Of these otoliths and scales are the most widely used because they are easy to collect and store. The thin bones of the head and of the pectoral and pelvic girdles have also been used. Although bones are easy to store dry, they are time-consuming to prepare. The flesh has to be removed by boiling them in water and then the fat removed in a solvent, otherwise they go rancid in storage. Vertebrae are commonly used for rajids, which do not have large bony otoliths and for tuna. Again these need time-consuming preparation. Ray vertebrea have to be cleaned in a boiling solution of sodium hydroxide and then stored in methanol. Tuna vertebrae are stored dry. Spines of some dogfish, Squalus acanthias are also used for regular age determination of this species in England.

When starting an investigation it is worth examining several different structures to see which gives the best results. In some instances two methods will complement each other.

As otoliths and scales are the two structures most widely used for age determination, only methods for reading these will be described. Most of these methods are equally applicable to reading the other structures with either no or slight modification.

4.2 Collection of Otoliths and Scales

4.2.1 Otoliths

The sagittal otolith is that used for age determination of most fish. It is located in the sacculus of the inner ear. The manner of cutting into the head of the fish to remove it depends on the type of fish. It amy also depend upon whether the fish are to be sold subsequently in which case damage to the fish must be kept to a minimum.

For flatfish, a cut in the position illustrated in Fig. 4.1a exposes the otoliths and they are easily withdrawn with forceps (Fig. 4.1c). When otolithing large numbers of flatfish the operation is speeded up by using a board with a slot, 3 x 10 cm, cut in the surface. The point of incision in the head of the fish is laid on the board over the slot; this enables the knife to be driven easily through the skull at point X (Fig. 4.1c), and the cut made cleanly in the correct position (Fig. 4.1b).

A number of methods can be used to extract otoliths from "roundfish" e.g. gadoids, the simplest being a transverse cut across the head, slightly behind the eyes, far enough into the skull to allow the head to be broken open. A knife or scalpel can be used for small fish but a normal metal hacksaw for larger sizes makes the operation quick and easy (Fig. 4.2). An inexperienced worker can easily cut too deeply and damage the otoliths, but the right tech-

nique is soon learnt. An alternative method is to lift off the top of the skull. This is a more difficult method, particularly with large fish, although there is less chance of damaging the otoliths (Fig. 4.3a). If the otoliths must be removed without apparent damage to the fish then it is possible to extract them from under the gill (Fig. 4.3b) or from the roof of the mouth.

4.2.2 Scales

The scale lies in a pocket in the skin of the fish and is divided by a horizontal line into two areas. The embedded area is covered with striations and concentric rings, while the exposed area is unstriated. Scales vary in shape depending on the contours of the fish. The best scales for age and growth rate determination are generally to be found on the shoulder of the fish between the head and the dorsal fin (Fig. 4.4).

The fish from which scales are to be taken should first be washed under cold running water. During the washing, the body of the fish should be rubbed lightly in a head-to-tail direction in order to remove any loose scales which may have rubbed off other fish. Using forceps, a scale is then taken from the shoulder of the fish. A slight resistance should be felt when it is pulled from its pocket in a head-to-tail direction. If no resistance is felt or if the scale is not observed to pull from its pocket, it is probably that it did not belong to that fish and it should be discarded. When a satisfactory scale has been taken, it should be cleaned by dipping in fresh water and rubbed between thumb and forefinger to remove any dirt or mucus. If sufficiently large, it should then be quickly examined by eye to check that the area covered with concentric rings is not damaged. Sometimes a scale is removed from its pocket at some stage in the fish's life; when this occurs, a new one is grown very quickly, but the new scale has a regenerated centre which makes it quite useless for age determination. Regenerated scales can easily be detected by the confused nature of the striations and the absence of concentric rings near the centre.

4.3 Storing and Mounting

Storage systems need to have the following advantages:

(a) Occupy the minimum space.
(b) Need no maintenance, such as the continuous refilling of tubes holding otoliths in a volatile liquid.
(c) Allow easy access and reference.

4.3.1 Otoliths

The most simple way, which can be used for the majority of species, is first to thoroughly clean the otoliths and then to store them dry in conveniently sized paper envelopes or plastic bags which are labelled and stacked in boxes. If it is necessary to keep the otoliths wet, then small sample tubes of the appropriate size should be used and the most suitable liquid selected. Alcohol or glycerine or alcohol/glycerine mixture or creosote may be used, but care should be taken to ensure that the ring structure on the otolith is not damaged or rendered unreadable by storage in an unsuitable medium. Formalin should not be used. Whatever liquid is chosen as the storage medium, it is advisable to check regularly its effect on the appearance of the otolith. In some cases short-term storage may make the rings more easily readable, but this may be followed by a period when there is a progressive deterioration in the clarity of the ring structure. Small otoliths, such as those of sandeels or mackerel, can be conveniently handled and stored by mounting a series in resin on a microscope slide (Fig. 4.5).

4.3.2 Scales

The scales should be mounted on glass microscope slides, the same way up as they came off the fish, that is convex side up. A scale is slightly curved in cross section and will curl

off the slide if mounted the wrong way up. The scales may stick directly to the slide once they have dried but in difficult cases either a spot of egg albumen or for very thick scales, gelatine containing a fungicide or bactericide (e.g. thymol) placed under the scales will help them to stick. Large scales, e.g. tuna, may be collected dry in small envelopes. When slides are used they should first be numbered in a set order so that it is possible to relate a particular scale with any data that may be recorded. When a slide has its predetermined number of scales on it, the scales should be levelled up one with the other. The line which divides the scale into two parts should be in a horizontal plane in the slide, with the area containing the concentric rings underneath. This will help when the scales are examined under the microscope at a later stage. It is usual to take two scales, one from each side of the fish, one to act as a check on the other (Fig. 4.6).

4.4 Methods of Preparation and Viewing

Methods of viewing otoliths and scales do have some aspects in common but as the otoliths is a three-dimensional structure and the scale almost two-dimensional, the techniques used for otoliths are generally more complex than those required for scales.

4.4.1 Otoliths

4.4.1.1 The structure of the otolith

As already stated otoliths are three-dimensional structures but they do not necessarily grow at the same rate equally in all dimensions. If there is a pattern in the otolith it will be composed of a number of concentric shells with different radii. Depending on the amount of organic material in each shell or zone, its appearance will vary from extremely opaque to completely hyaline (transparent). When reading otoliths it is usually preferable to identify and count the opaque zones. If any characteristic growth patterns are visible in the otolith they will usually appear opaque zones. In the simplest case one complete cycle of otolith growth (e.g. an annual cycle) consists in the laying down of one opaque zone and of one hyaline zone. The first zone is usually called the 'nucleus' of the otolith.

The two types of zones or rings must never be referred to as "light" and "dark". This only creates confusion, because the method of illuminating the otolith determines whether a zone appears as a dark or light ring (Fig. 4.7). The terms "summer zones" and "winter zones" should also be avoided. It is also best to avoid the term annuli unless it is certain that the rings or zones are annual.

4.4.1.2 Viewing the fresh otolith

The ring structure may be most easily visible immediately the otoliths are removed from the fish. If so, then every effort should be made to read them at that time. For some species it may be the only time at which they are readable.

4.4.1.3 Viewing the whole otolith

To view an otolith a number of techniques are available. The simplest of these is to immerse the whole otolith in a clear liquid (water is quite commonly used), illuminate it from above, and view it against a dark background. This method is suitable only if the otoliths are relatively thin and translucent and all the rings can be seen (Fig. 4a). In many species the outer rings become very narrow once the growth rate of the fish slows down. These narrow rings sometimes grow only on the underside of the otolith, and are completely invisible when the whole otolith is viewed from above in the manner described (Fig. 4b). They can be seen only when a cross section of the otolith is viewed (Fig. 4c). When investigating any species of fish it is always necessary to check, by examining a cross section, whether these narrow rings are present before accepting an age based on viewing the whole otolith from above. Failure to understand this type of growth pattern in otoliths can result in gross underestimates of age.

It is not possible to see the narrow outer rings more clearly by grinding either surface of the whole otolith and then viewing it from above. Grinding the otolith will make it more translucent but the rings on the underside will still not be visible from above, and grinding may remove some of the rings completely (Fig.4.8d).

4.4.1.4 Preparing a cross-section of an otolith

When the structure of an otolith makes it necessary to view it in cross-section then a number of possibilities exist, either longitudinal or transverse or diagonal. All these alternatives, illustrated in Fig. 4.9, need to be investigated before the most suitable section for routine age determination is chosen. It is frequently found that a very slight change in the angle of a cross-section will help with the interpretation of a difficult otolith.

A simple grinding machine, for making cross-sections only, enables a wide variety of otolith sections to be prepared, with the certainty that each section is across the nucleus (Fig. 4.10). After a little practice it is quite simple to break larger otoliths at the required place with the fingers or by holding one end of the otolith firmly in a pair of forceps. If by accident the break occurs off centre, it is a simple matter to correct this by using the grinding wheel. Wetting the surface of the otolith with water or cedar wood oil, applied with a fine paint brush, fills in any irregularities caused either by grinding or breaking and makes the otolith much easier to read.

Whatever method is used to prepare the otolith it is necessary to ensure that the section is taken across the centre of the nucleus. Failure to do this can lead to a number of errors in interpretation. If the break misses the nucleus completely then the first ring will appear to be the nucleus and the age will be underestimated by one year (Fig. 4a). If only the tip of the nucleus appears on the section then the whole appearance and spacing of the rings will be altered, making it easy to misinterpret. Possibly the true nucleus will be ignored, but certainly some confusion will result (Fig. 4b). Only when the section passes through the centre of the nucleus will the true size of the nucleus and rings and their relationship to one another be clearly visible (Fig. 4c).

To section an extremely small otolith, e.g. that of an eel, the otolith should be placed on a microscope slide and either covered with sellotape or sandwiched in sellotape before being placed on the microscope stage. If illuminated from below it is easy to identify the nucleus and, by pressing on it with a scalpel, to break the otolith directly across it. The sellotape will prevent the very small broken halves from being scattered.

Once a satisfactory section has been prepared it can be viewed either by transmitted light or by illumination from above or after being burned in the manner described by Christensen (1964).

4.4.1.5 Viewing the cross-section with transmitted light

The majority of readers of gadoid fish otoliths in Europe use the transmitted light method of illumination. The prepared section is mounted in plasticine with the surface to be viewed horizontal. The otolith is then illuminated from the side and the sectioned surface placed in shadow. This method offers considerable advantages over the method of direct illumination from above because it allows the reader to see more of the detailed structure of the otolith (Fig. 4.12a).

A simple device used at the Fisheries Laboratory, Lowestoft allows the reader to put the surface of the section into any degree of shadow required, which may well be different for parts of the otolith. This device consists of an adjustable height bar. A brass base plate supports a vertical pillar in which is housed a captive threaded rod. By turning this thread the bar is raised or lowered to the height required (Bedford, 1964) (Fig. 4.12b).

4.4.1.6 The burning technique

Rings on the otolith of some species of fish, e.g. soles (Solea solea), are not visible when viewed by any of the methods already described, and the narrow outer rings and split rings of other species, e.g. plaice (Pleuronectes platessa) and turbot (Psetta marina), often present considerable difficulties. If the prepared cross-section is gently burned over a very low flame of either a small Bunsen burner or a spirit lamp until it is slightly charred, then the appearance of the existing rings is changed and a narrow black ring is produced at each change from hyaline to opaque material reading outwards from the nucleus of the otolith. (Christensen, 1964).

The amount and rate of burning varies between species and the technique required to achieve the best results has to be learnt. Care must be taken to burn the whole of the sectioned surface of the otolith evenly. If the otolith is burned too much it will crumble into a grey ash; this usually occurs first at the edges of the section and it results in the complete disappearance of the ring structure. If insufficient heat is applied then the organic zones will not char.

To achieve the best results the centre of the sectioned surface should be held barely touching the side of the flame and removed when it begins to turn dark brown. If after examination, it is found to require additional burning then it is a simple matter to return it to the flame until the desired result is obtained. After being burned the otolith is picked up on a piece of plasticine which enables it to be moved under the microscope to any desired position.

Each black ring encloses a white area representing the total growth during one year. A large number of extremely fine hair-like concentric black rings can be seen in the white zone, but the true, much thicker black annual ring is clearly distinguished (Fig. 4.13).

The use of the burning technique makes it possible to age species whose otoliths were previously impossible to read and to increase the accuracy of age determination of many other species, particularly those of the older fish whose age had been constantly underestimated in the past by other techniques. Problems of nucleus difficulties and false rings can often be resolved after burning. The otoliths of all species do not burn in this way.

Often a good technique is to use a combination of different viewing methods, e.g. whole otolith, illuminated from above against dark background, and sectioned-burned or unburned otolith. Queries arising from one method can sometimes be resolved by using the alternative method on the second otolith of the pair.

4.4.1.7 Unusual growth zones

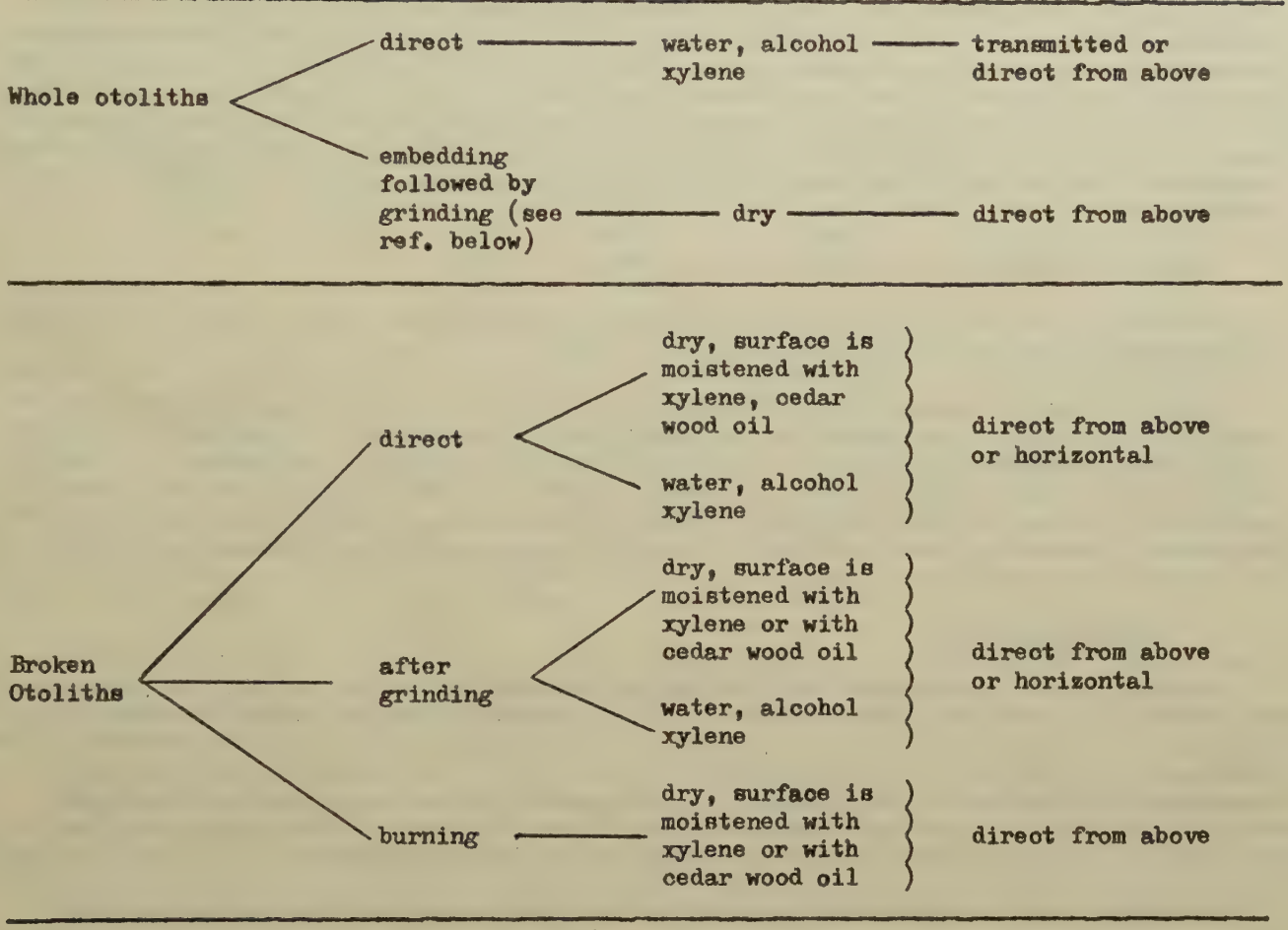
Sometimes a particular year will produce unusual growth zones. For example, the opaque zone may either be exceptionally wide or have a check in the middle or have some other unusual characteristic which is easily recognizable.

The examples that have occurred in the otoliths of North Sea plaice were found in the 1944 and 1947 year-classes. Fish from the 1944 year-class often had an extremely thin 1946 opaque zone that was easily recognized; this thin zone sometimes occurred in up to 20 percent of a sample of fish of the 1944 age group (Fig. 4.14). Many of the 1947 year-class fish had a distinctive triple nucleus; this was found in 0 and 1 group fish along the Dutch coast and could be identified many years later in older fish taken from the central North Sea (Fig. 4.15).

Although these unusual zones often create difficulties of age determination when they are being formed, once the difficulties have been resolved they serve as a useful check on the validity of the age readings many years later by acting as a biological mark on the otolith. However, one must always guard against the danger of becoming too familiar and thus holding unfound assumptions. Always be objective.

Table 4.1. Methods for Age Determination

Otoliths



Otoliths age reading by means of surface structure examination from
S. Wiedeman-Smith (1968)

A summary of all the methods of reading otoliths is given in Table 4.1.

4.4.2 Scales

4.4.2.1 The structure of the scale

Scales are almost two-dimensional structures. The anterior part is formed of a series of sclerites which should extend in a regular pattern from the centre of the scale (Fig. 4.16). If they do not and they are confused or irregular then the scale is almost certainly a replacement scale and should not be used for age determination. The structural discontinuities used for age determination result from irregularities in the pattern of the sclerites; they may be slightly distorted (Fig. 4.16) or they may be slightly closer spaced than the majority of the sclerites; usually the discontinuities are narrow and they are usually called 'rings'; as stated earlier the term 'annuli' should not be used because this presupposes that the rings are annual. Thus the scale presents a different picture to the otolith.

4.4.2.2 Preparing and viewing scales

Because scales are thin structures they need no preparation before viewing; the scales should be cleaned before they are stored.

For reading, the slide on which the scales are mounted is placed on the stage of a low-power microscope. The mirror and condenser are removed from the microscope, and light from a lamp is reflected through the scale by means of a piece of white card or reflector. The field of the microscope should appear dark apart from a small segment at the bottom which should be very bright (Fig. 4.17). The magnification used depends upon the size of the scale; in general, the lowest possible magnification is the best because it enables the whole scale pattern to be seen.

4.5 Other Techniques

Staining can be used to intensify structural discontinuities or to make visible those not available by ordinary light. Galstaff (1952) describes a method of staining tuna vertebrae with alizarin but it takes up to 12 days' preparation. This demonstrates the disadvantage of methods based upon staining; they are too time-consuming for processing large amounts of material, even though batch processing will allow a quicker throughput. However, if staining is the only method which will show discontinuities then it must be used, even if it does result in smaller numbers of age determinations.

Polarized light and phase differentiation are also techniques that can be used.

4.6 Validation

In this section it is assumed that some pattern of structural discontinuities (for ease of reference termed 'rings' for both otoliths and scales, except when referring specifically to one of the structures) exists in the structure which is being used for age determination and that it has been made visible by some technique. The next step is to determine whether any time-scale can be allotted to the pattern of rings. This time-scale need not be annual. There are several ways in which to do this.

(a) by observing the timing of ring formation;
(b) by following a strong year-class through the fishery;
(c) by using the Petersen method.

4.6.1 Timing of ring formation

The opaque zone in the otoliths of North Atlantic species of fish is formed during the period of greatest growth and it is usually wider than the hyaline ring, particuarly during the early years of the fish's life. The hyaline zone is laid down mainly during the period of slowest growth. But the timing of ring formation is considerably more complex than this simple statement suggests.

Although the opaque zone is sometimes referred to as a summer zone, the timing of its formation can vary considerably, depending upon the species of fish, where it lives and its age. In general in the northern hemisphere, the opaque zone starts to grow earliest in the southern part of the species' range and begins later with increasing distance north. Within each area the younger fish begin to lay down the opaque zone before the older fish. In the North Sea the otoliths of a young cod may show the beginning of an opaque zone in February but an older fish may show no signs of it until June. A similar difference in the timing of opaque zone formation between young and old fish also occurs in the north-east Arctic, but the whole process is delayed by about two months; the opaque zone in the older fish may still be visible on the edge in January of the following year. This is illustrated in Fig. 4.18.

The type of zone forming on the edge of the otolith can be recorded from a series of samples taken throughout the year. Then, provided that the zones are annual, the growth pattern shown in Fig. 4.19 should be observed. This series of plaice otolith photographs clearly illustrates both the timing of zone formation and the rate of growth of the otoliths during a year and there can be no doubt that the zones are annual. It should be noted that all these fish belong to the same age group 4, and have been caught during one year in the same area (central North Sea). There can be a wide variation in the timing of the formation of zones from year to year within a single species, between different areas and between fish of different age groups. All these factors must be considered when attempting to collect data to confirm the timing of zone formation.

When the samples are taken from a wide range of age groups from different areas, then the seasonal difference in type of edge is not likely to be as marked. If sufficient otoliths are available, the type of edge present should be recorded separately for each age group from each area.

Exactly the same techniques can be used for determining the time of ring formation on scales. The change in this instance is not between one type of material and another but in the formation of the sclerites.

This method can be validly used whatever the period of the time-scale over which the rings are laid down (for example, six months) as long as the sequence is regular.

4.6.2 Following a large year-class through the fishery

If a series of otolith or scale samples are available for a number of years from a stock, it is often possible to confirm the validity of age determinations by identifying a large year-class and following it through the fishery for several years. If the techniques used are sound, then a number of independent readers, each given a different year's otoliths or scales should all produce an age composition showing the dominant year-class; this was the way in which the early North Sea sole otolith readings were confirmed.

4.6.3 The Petersen method

This method is named after the Danish fisheries' scientist G.G. Joh. Petersen, who first described it. It depends upon the following sequence of observations:

(a) a length distribution of the species being studied has several modes which are readily separable;
(b) observations of the otoliths or scales of the fish of each length show that almost all the fish which constitute a length mode have the same number of zones or rings on their otoliths or scales.
(c) the reason for the origin of the modes can be determined, enabling a time-scale to be placed on the zones or rings.

The use of this method will be described in more detail in section 4.11.1.

4.6.4 Injection techniques

Artificial time markers can be introduced into skeletal structures by injecting chemicals into fish. The initial work was based on the use of lead acetate but this is toxic and tetracycline is now commonly used. It has the advantage of being an antibiotic drug, stable in solid form. It is used in saline solution which must be used immediately or within 24 h if kept in refrigeration.

Tetracycline is readily absorbed by vertebrate animals and deposited in bony structures where calcification is taking place. The areas in which tetracycline is deposited in skeletal tissue fluoresce yellow in ultraviolet light, enabling them to be detected easily.

In teleost fish, which possess acellular bone, the tetracycline is laid down as a narrow ring timing the point of injection to within a month, the time taken to completely excrete excess tetracycline (Fig. 4.20). In elasmobranchs, which have partially calcified, cartilaginous, cellular bone the tetracycline is laid down diffusely throughout the skeleton present at the time of injection. Parts of the skeleton laid down subsequently contain no tetracycline.

Initial tank experiments are carried out, if possible, to determine the optimum dose rate of tetracycline. In the field the fish have to be tagged, as well as injected, because the technique does depend upon retrieving the injected fish so that their otoliths and scales can beexamined. In the North Sea the method has been used for cod and whiting (Jones and Bedford, 1968) and for rays (Holden and Vince, 1973).

4.7 Allocation of a Birthday

When it has been possible to view the zones or rings, count them satisfactorily and establish that their formation conforms to a definite time-pattern, then it is possible to age the fish. In the remainder of this section if will be assumed that the fish have one spawning period a year and that the zones on its otoliths (rings on its scales) have an annual pattern of formation.

The terms age, age group and year-class are frequently used. The age of a fish at a given time refers to the period of time from birth to a given point of time. When the age of the fish has been established it can be assigned to the appropriate age group which is an integral number of years, according to a convention based on an arbitrarily-adopted birthday. Fish said to be of a given year-class are fish born in that particular year.

To simplify aging, age determinations are usually done in terms of age groups with reference to a designated birthday. This birthday does not have to coincide with the biological time of birth. For convenience, there is a convention to use 1 January for most Atlantic species, even though the time of spawning of some members of a species may be in the December of the previous year and other species may not finish spawning until May. This system of identifying fish by age groups is shown schematically in Fig. 4.21 and by photographs of a set of North Sea plaice otoliths in Fig. 4.19. In the latter figure the fish of age group 4 have four opaque and four hyaline zones in January. By June the fifth opaque zone is

visible but it does not become a 5-group fish until 1 January 1972. For the whole period 1 January 1971 to 31 December 1971 it is a 4-group fish. Its true age on 1 January 1971 would be 4 years exactly (assuming it was spawned on 1 January 1967) and on 31 December 1971 4 years, 11 months, 31 days.

The great advantage of this method is that it enables the year-class of a fish to be established immediately by subtracting age group from year of capture (in the above example 1971 - 4 = 1967) and it permits easy grouping of data collected by different laboratories. The method does require good knowledge of the pattern of zone or ring-formation because it may be necessary to discount zones or rings that have already formed (the fifth opaque and hyaline zones in the plaice shown in Fig. 4.19 from June to 31 December) or to assume that a zone or ring should have been formed but it is not yet visible. This is shown diagnostically in Fig. 4.18; the opaque-zone of a 15 year old Arctic cod is not visible until the January of the year after which it is laid down; that is, the 1973 opaque zone is not visible until January 1974. In November and December 1973 it is necessary to take this into account and not count the visible hyaline edge as the edge-forming in the 1973-74 winter.

Notations such as age 4 + carry the same meaning if the same systematic convention described above is used but notations such as 4 ++, 4+++ or even 4++++, the last meaning a fish almost 5 years' old, are so meaningless that they have no value. The terminology '3 ring fish', '4 ring fish, is also confusing unless it is known that all rings are consistently laid down within a very restricted time period. For example, a species for which 1 January is the official birthday may normally lay down its scale rings in December. A fish chronologically aged 4 years (say, born theoretically on 1 January 1967 and caught on 14 January 1971) will be called a 3 ring fish if it has not laid its fourth ring down by that date.

4.8 Special Uses for Otoliths and Scales

4.8.1 Spawning zones

Some species exhibit a different ring structure after the onset of spawning. In Arctic cod the post-spawning opaque zones are extremely narrow and regular. These post-spawning zones can be identified, counted and the otoliths used to provide data on the number of times each fish has spawned, in addition to giving the age (Rollefsen, 1933) (Fig. 4.22a).

One feature that can be observed on the otoliths of mature cod is the wider and brighter hyaline zones that sometimes occur immediately before the first post-spawning opaque zones.

4.8.2 Stock patterns

The otoliths of the same species of fish from different areas are often quite different in appearance, reflecting the different growth pattern of the fish. An experienced otolith reader is often able to identify, with considerable precision, the origin of a sample of otoliths taken from an area where a mixing of stocks occurs. Three distinctive cod types from the north-east Arctic north of Norway are illustrated in Fig. 4.22.

(a) from the eastern Barents Sea;
(b) from the western part of the area; and
(c) the resident coastal type.

Types (a) and (b) are found in members of the stock which have lived in different parts of the north-east Arctic; type (c) is from a different stock the Norwegian coastal stock.

Differences in the size of growth zones on scales (distance between two rings), particularly the first growth zone, are used to separate stocks of North Sea herring. Also the country of origin of North Atlantic salmon can be determined by the number of growth zones laid down while they are in freshwater during the early part of their life when the growth rate is much slower under these conditions than in the sea (Fig. 4.23).

4.9 Some Difficulties and Possible Sources of Error

4.9.1 Differences between otoliths from the same fish

There can be differences in the number of rings present in the two otoliths taken from the same fish. Fortunately this is an extremely rare occurrence and can usually be detected by a fairly superficial examination of both otoliths, when a deformity in the shape or structure of one or both otoliths is easily visible. Scales rarely differ unless one is a regenerated scale or unless they are taken from different parts of the body.

4.9.2 Variation of age at length

It is not at all uncommon for the growth ratesof the same species of fish taken from the same area to show an extremely wide variation. For example, the ages of small North Sea plaice in the 5 cm size group 25–29 cm can range from 1 to 7, the 1 group being most likely to occur in December when their actual age is 1 year and 11 months' old. The 5 cm group 30–34 cm could contain fish between2 and 12 years' old, and among the larger fish (45–49 cm in length) the age could lie between 7 and more than 20 years.

Wide variations in growth rates also occur in other species and great care should be taken not to fall into the error of first looking at the length of the fish from which the otoliths have been taken, deciding what the age is likely to be, and then looking at the otolith or scale and attempting to make the preconceived age fit the visible structure, either by grouping or omitting rings.

A similar error is to attempt to define size limits within which the nucleus or zones must fall, based on the size of zones found on other otoliths. A slow-growing fish may have three or four annual zones occupying the same space as one or two zones on a fast-growing fish (Figs. 4.2.4 and 4.2.5). It is therefore impossible to say that some zones must be false because three or four narrow annual zones occupy the space of one very wide annual zone. These comments apply also to scales.

EITHER THERE ARE RECOGNIZABLE RINGS THAT CONFORM TO A REGULAR TIME-SCALE ON THE OTOLITH OR THERE ARE NOT. LENGTH IS NOT A CRITERION OF AGE.

4.9.3 False rings and check zones

The main source of difficulty in otolith reading is to distinguish as certainly as possible the true annual zones from secondary, false, split or check zones. If the otolith burns satisfactorily this usually clears up any queries. It is usually assumed that any ring on a scale which runs round the whole of the anterior edge is a 'true ring' and is counted and that one which does not do this is a 'false ring' and is not counted. Solutions to these problems can be gained only by study of the species under investigation.

Age determination is a skill which has to be learnt. Some people become more proficient at it than others; some never become competent. While the European Inland Fisheries Advisory Commission (EIFAC) is preparing a scale atlas based on fish of known age, the whole purpose of reading scales and otoliths is to determine the age of fish whose age is unknown and whose absolute age will always be uncertain. The best reader in the world cannot state with 100 percent certainty the exact age of a wild fish.

To avoid errors and systematic bias, frequent cross-checking of results between readers and by the same reader repeating the reading of a sample at a later date will ensure that no wide differences of interpretation occur and that the readings remain consistent. Readers must always be objective.

4.10 Causes of Zone and Ring Formation

Any major change in the environment in which a fish lives is likely to produce ring formation (in this sub-section ring and zone formation will be considered synonymous). In the earth's temperate zones differences between summer and winter are marked by both changes in water temperature and amounts of food available. It is these very regular and very marked changes which make the age determinations of most temperate fish species so easy. But equally marked changes occur within the tropics. Many rivers in the tropics are subject to seasonal floods. During the floods food is abundant and the fish grow rapidly. In the dry season food becomes very scarce and the fish often starve. This results in very marked rings forming on the scales. Examples are the Gambia (Svensson, 1933) and the middle Niger (Daget, 1956). In Lake Chad (Hopson, 1965) has described how the fall in temperature in November-January causes the formation of rings on the scales of Lates niloticus. Poinsard and Troadec (1966) describe the age determination of Pseudotolithus senegalensis and P. typus, two West African marine species, both of which lay down two opaque zones during two warm seasons and two hyaline zones in two cold seasons. Mature fish of the former species spawn twice a year.

Garrod (1959) aged Tilapia esculenta in Lake Victoria by proving that the rings which occur at the edge of the scale were laid down at spawning. A time-scale was allotted to the rings by then proving that this species spawned twice a year in the north of Lake Victoria and once a year in the south. (Seshappa, 1969) describes a similar study to that of Garrod, using the rings caused by spawning that form on the scales of Indian mackerel Rastrelliger kanagurta. Seshappa also examined the otoliths of this species but found no zones on them.

When faced with the age determination of a new species the first question must be 'Has it got rings on its scales or zones on its otoliths which can be read by some method?'. The second question must be 'What causes these rings or zones so that a time-scale can be set to them?'. The regularity of the event causing ring formation must be checked to determine that no other events will lay down rings similar to the main seasonal rings. This is most likely to happen if the species being studied is living in a small volume of water, such as a small lake or pond. In temperate zones the main rings may be caused by summer-winter variations in the environment but other events may produce rings identical to annual ones. These events might be either plankton blooms or sudden unseasonal changes in temperature or accidental discharge of pollutants, to quote three possible examples.

However, some fish live in uniform environments, notably in the polar and tropical regions and consequently no rings whatsoever are laid down in their skeletal structures.

4.11 The Indirect Age Determination of Fish

4.11.1 The Petersen method

This method has already been referred to in section 4.1.6.3. In that section it was referred to as a means of age validation of fish which had discontinuities in their skeletal structures. The method can be used only with species which have a restricted spawning season so that the fish bred in a single season can be identified as a single mode in a polymodal length distribution. The mode with the lowest value is identified as soon as possible after spawning; these will be 0-group fish. Subsequent modes will be 1-group, 2-group fish and so on. The method can be very good for young fish but becomes increasingly less useful for older fish as the growth rate slows down and the modes merge.

In practice length-frequency distributions of fish are plotted caught over the shortest time period possible; the shorter the time period the more precisely the modes will be defined. A regular sequence of such length frequency distributions enables the progression of the modes to be followed.

The following examples illustrate the problem.

(a) Sardinella aurita

In this tropical species age determinations by otoliths and scales is not easy but the length frequency distribution ages those with a mode at 11.5 cm as 0-group and those with a mode at 18.5 cm as 1-group.

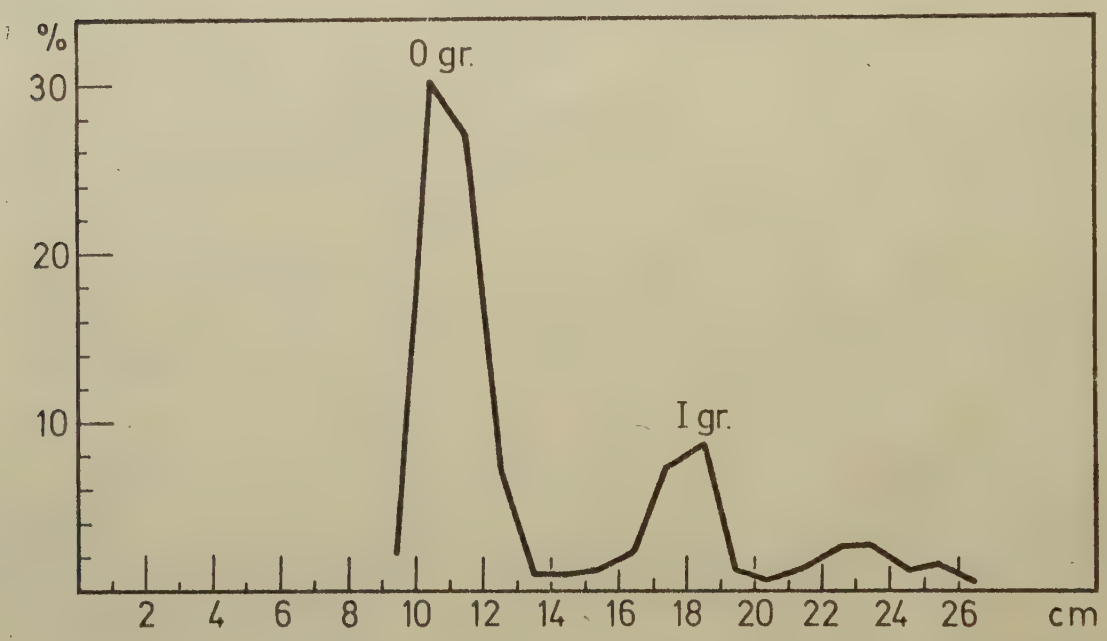


Fig. 4.26. Sardinella aurita. Ghana, Feb. 1968. Length distribution in the purse-seine landings.

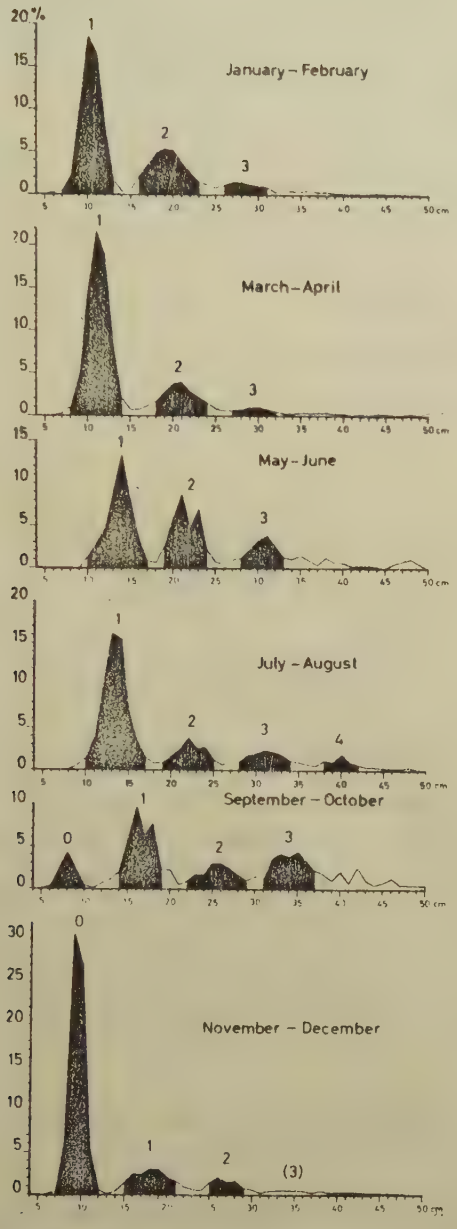
(b) The Greenland halibut (see next sheet)

4.11.2 Tagging

Tagging does not enable individual fish to be aged unless the age of the fish at tagging is known indirectly, for example, by using hatchery reared fish or known 0-group from the Petersen method. Otherwise, all that is known is that recaptured tagged fish must be at least as old as the number of years for which they have been at liberty. Growth parameters can be calculated from the recaptures of tagged fish (Gulland and Holt, 1959). The method described in this paper is very useful for fish living in areas where the growth is continuous throughout the year, because it is based on this assumption. It is less useful where this assumption does not hold, but it can be used if large numbers of fish recaptured at annual intervals are available (Jones and Jonsson, 1971).

However, changes in the growth rate caused by both the tag and the tagging procedure often occur. Therefore, the growth of the recaptured fish cannot be taken as a representative of that of unmarked fish in the population in the same period.

(b) The Greenland halibut (Reinhardtius hippoglossoides Walb.)



The age of this Arctic species can not be determined by the use of otoliths and scales, but the length distribution gives a good estimate of the length of 0-, I-, II- and III-group fish. Furthermore, it is possible to follow the growth of the year-classes during the year (data from Smidt, 1969).

Fig. 4.27. The Greenland halibit (Reinhardtius hippoglossoides Walb.) Godthåb, 1953-63. Changes in the length distributions during the year.

4.12 Determination of Growth Rates from Scales and Otoliths

As the scale grows at approximately the same proportional rate as the fish, it can be used for growth rate determination. This relationship, which may be linear or curvilinear, can be determined by plotting scale size (V_n defined below) against fish length. If it is linear the length of the fish when each ring was laid down on the scale (referred to as l_1, l_2, l_3 ..... l_n) can be calculated using the formula

$$l_n = \frac{L.V_n}{V} + c$$

where l_n is the length of the fish when the n.th ring is laid down

V_n is the length of the striated part of the scale to the n.th ring

V is the total length of the striated portion of the scale

L is the total length of the fish

c is a constant

If c = 0 or is small, values of l, l_2, etc., can be calculated easily as follows.

To calculate this relationship automatically a simple proportioning board can be used (Fig. 4). It consists of a graduated rule fixed to the right-hand side of a polished board at right angles to the bottom edge. This edge is lipped. An ungraduated rule, pivoted at the bottom left-hand corner of the board and long enough to overlap the top right-hand corner, completes the device.

To use the board an image of a scale is projected onto a rectangular piece of white card. The bottom end of one edge of the card is placed on the nucleus of the projected scale, and the positions of the rings and the edge of the scale are marked on the edge of the card at an angle of 90° to the baseline. The marked card is then positioned on the board with the edge of the card corresponding to the nucleus flush with the lip at the bottom of the board. The lower edge of the diagonal, ungraduated scale is then placed at that length on the graduated rule at the right-hand edge of the board which corresponds to the length of the fish. The card is then moved along so that the line which marks the edge of the scale is directly under the lower edge of the ungraduated rule. This rule is then pivoted and placed directly over each of the marks on the card and the appropriate length is read each time from the graduated rule on the right.

Griffiths (1968) describes a more sophisticated electronic proportion device which automatically presents the growth data on the scale of a digital voltmeter.

As c becomes increasingly greater or smaller than zero so the values of l_1, l_2, etc., become increasingly incorrect using this method, the error being greater for l_1 and decreasing progressively toward l_n.

It is much less easy to back-calculate lengths from otoliths than from scales. In whole otoliths the edges of the zones are rarely well-defined and in sectioned otoliths the same difficulty exists. In addition there is the difficulty of sectioning the otolith accurately across the middle of its nucleus. As already described in section 4.4.1.4. the relative size of the zones depends upon the point at which the section is made. Small differences in the point at which the section is made may be perfectly acceptable for age determination, but can result in a considerable difference in the size of the zones that are visible for measurement. A series of transverse sections taken through the nucleus of the same otolith will show considerable differences in both the shape of the otolith and the size of the rings (Fig. 4).

If measurements are made on otoliths they are taken with a calibrated graticule fitted in the eyepiece of the microscope. Projection techniques cannot be used because the intensity of illuminations is too low.

4.13 Age Compositions

The proportion of different age-groups of fish in a catch or in the population is called its age composition. If the problem is to get an estimate of the age composition of a single catch of one species this is simply done by determining the age of all the fish in the catch. Table 4.2 shows the age composition of 200 fish of one species taken in a single trawl haul; the age of every fish caught was read.

Table 4.2

Age Composition of a Trawl Catch

Age:	II	III	IV	V	VI	
Numbers:	24	102	45	20	9	Total 200
%	12.0	51.0	22.5	10.0	4.5	Total 100

The results in the table can be shown in a histogram (Fig. 4.30).

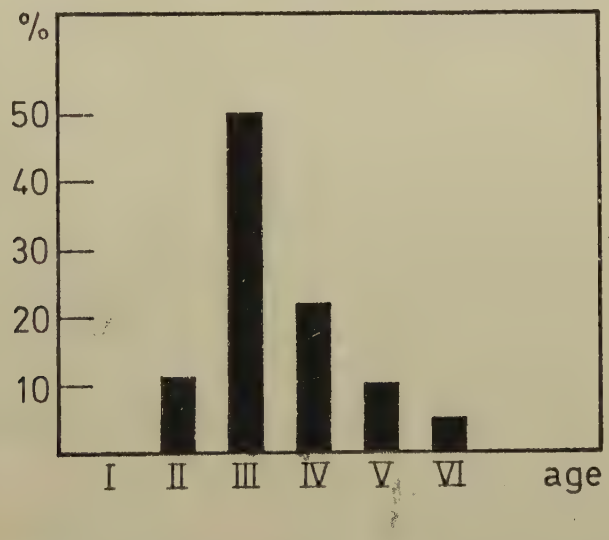


Fig. 4.30. Age composition of a hypothetical catch.

4.13.1 Use of age-length keys

In the previous example the age composition of a single, small catch was determined but normally that of the total landings is required. Every year this may total several million fish of each species landed and obviously it would be impossible to age each fish individually. Instead, an age-length key is constructed and used with the length composition data to estimate the total age composition.

The principle behind constructing an age-length key is that the length range occurring in the landings is split into length strata of equal length range, for example, 5-9 cm, 10-14 cm, 15-19 cm or 3-4 cm, 5-6 cm etc. The length range of each stratum will depend upon the growth rate of the species. For slow-growing fish the strata need to be smaller than for fast-growing fish. Usually a maximum of twenty length strata is sufficient.

Having decided upon the length strata a certain number of otoliths (scales, bones) are collected from randomly-taken fish in each stratum. How the number of fish taken is calculated is described in section 4.4.2.1. The ages of these fish are determined and an age-length key constructed. An example is shown in Table 4.3, which is for whiting caught off Scotland.

Table 4.3. Age-length key for whiting, trawl, Outer Hebrides. January-March 1968 (data from: Statistical News Letters No. 46, p. 142, 1968

Age	1	2	3	4	5	6	7	8	9	10+	Total numbers read
Year-class	1967	1966	1965	1964	1963	1962	1961	1960	1959	1958+	
Length groups cm											
28-9		13	2								15
30-1		18	2	2							22
32-3		12	10	10		4					36
34-5		3	14	11		12					40
36-7			15	9		16					40
38-9			9	16	1	14					40
40-1			4	16		19		1			40
42-3			4	15	1	18	2				40
44-5				8		29					37
46-7				5		25	3				33
48-9				1		17	1				19
50-1					1	5	2				8
52-3						4					4
54-5						2	1				3
56-7											-

The length strata (or length groups as they are described in the table) are 2 cm. A total of 377 whiting were aged of which 15 fish were in the 28-9 cm length stratum, 22 fish in the 30-1 cm stratum and so on. In the total example 46 fish were aged 2 years' old, 60 fish 3 years' old etc. However, these fish were selected by strata so the age data in the bottom row do not represent the age composition of the catch. They must be combined with the total numbers of fish landed (Table 4.4).

Table 4.4. Whiting, Outer Hebrides, trawl, January-March 1968. Estimated numbers in total catch by 2-cm length groups and age (data from: Statistical News Letters No. 46, p. 142, 1968, changed and rounded off (ICES, 1970)

Length groups cm	Total numbers landed	Age						
		2	3	4	5	6	7	8
28-9	8,100	7,020	1,080					
30-1	13,147	10,757	1,195	1,195				
32-3	21,248	7,083	5,902	5,902		2,361		
34-5	39,068	2,930	13,674	10,743		11,721		
36-7	40,502		15,188	9,113		16,201		
38-9	48,540		10,921	19,416	1,214	16,989		
40-1	28,351		2,835	11,340		13,467		709
42-3	28,351		2,835	10,631	709	12,758	1,418	
44-5	15,204			3,287		11,917		
46-7	20,251			3,068		15,342	1,841	
48-9	8,100			426		7,248	426	
50-1	3,302				413	2,064	825	
52-3	1,246					1,246		
54-5	2,306					1,537	769	

From Table 4.3 we know how the age groups are distributed in the different length groups. In the length group 28-9 cm 13 fish out of 15 (= 86.67%) were two years' old and 2 fish (= 13.33%) were three years' old. (From now on it is assumed that the percentage of each age group in each length stratum is a valid sample applicable to the landings). Therefore, 86.67% of the total number landed in the 28-9 cm group (8,100 fish) are two years' old, and 13.33% are three years' old, i.e. $86.67 \frac{.8100}{100} = 7{,}020$ fish are two years' old and $13.33 \frac{.8100}{100} = 1{,}080$ fish are three years' old. The calculated values for all other length groups are seen in Table 4.4. The sum of each column gives an estimate of the total number landed in each age group.

Calculation is easier if a raising factor is used for each length group. This is obtained by dividing the total number landed by the total number aged for each length stratum. For the 28-9 cm group this is: $\frac{.8100}{15} = 540$. Multiplying this factor by the number of fish of each age in the age length key gives the number of fish in each age group, e.g. : $540.2 = 1{,}080$. The final result is shown in Table 4.4.

If mean lengths for age are required for constructing growth curves the age composition data (Table 4.4) MUST be used, NOT the age-length key (Table 4.3).

The results in Table 4.4 are shown as a histogram in Fig. 4.31.

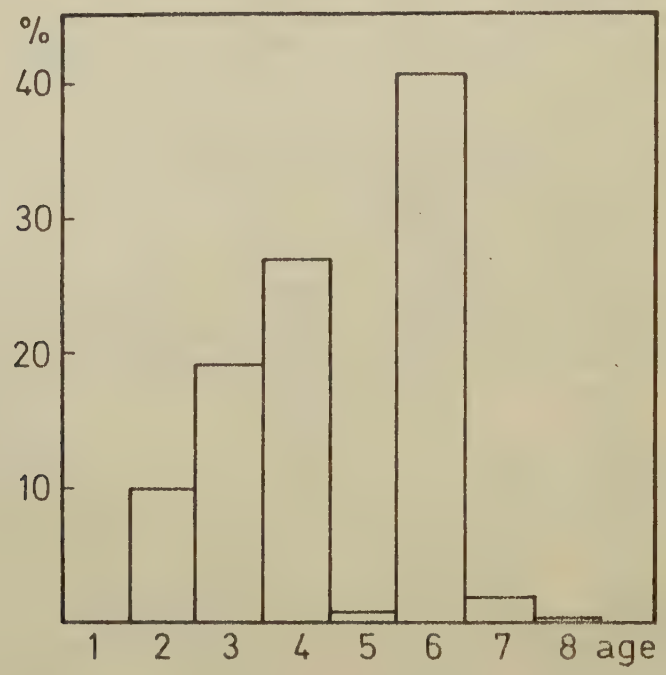


Fig. 4.31. Age composition of whiting. Outer Hebrides, January-March 1968, trawl.

Such histograms can be obtained for a number of years and it is possible to put all these figures together. Fig. 4.32 shows the age distribution in the landings of sole for a number of years on the west coast of Jutland. The black columns in the figure correspond to large "year-classes". (In some species there are very great fluctuations in the annual recruitment and there is a corresponding variation in the proportions of the age-groups in the population. In the Danish sole fishery the large year-classes are those of 1958 and 1963 and they can be followed in the catches for several years. Such large year-classes are the basis of many fisheries and their absence can cause a serious reduction in the catch.

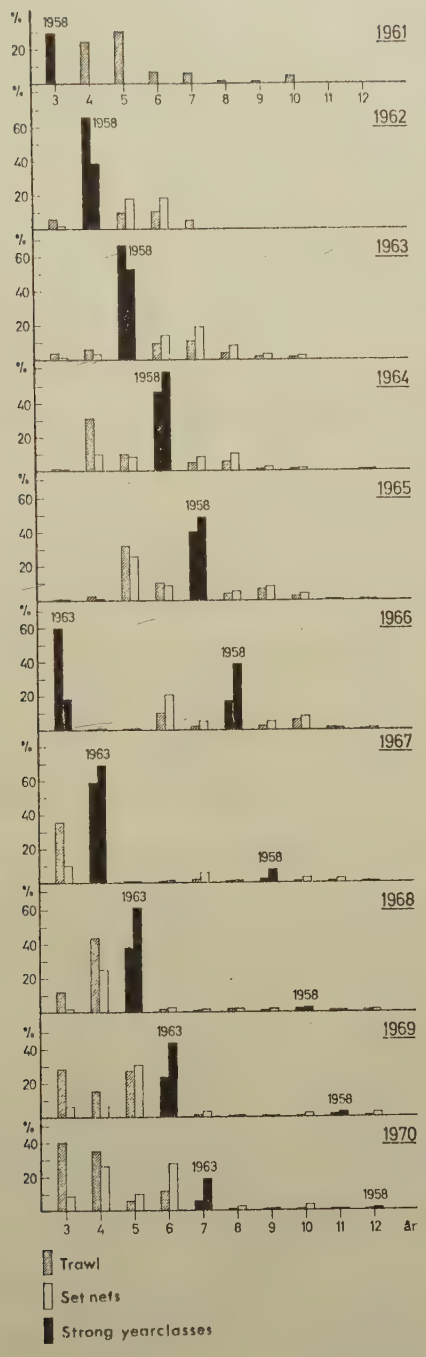


Fig. 4.32. Sole, North Sea, age composition of the landings in Hvide Sande, 1961-70.

4.13.2 The number of fish to age

The number of fish sampled for age is a question of money and time. The precision will be improved by any increase in sampling but the time (and money) spent will increase too. A balance between the precision required in these estimates and the time used to get this precision has to be struck.

The variance in each length group of the estimated numbers of fish age i can be written down:

$$\text{Var } N_i = N^2 \cdot \frac{1}{n} p_i (1-p_i) + p_i^2 \cdot \text{var } N \qquad (1)$$

The coefficient of variation of N_i is:

$$= \sqrt{\frac{(1-p_i)}{n \cdot p_i}} \qquad (2)$$

where in a certain length stratum

N	=	number of fish in the landings
n	=	number of fish sampled for age
p_i	=	number of fish in the age-length key at age i, in fractions
$n \cdot p_i$	=	number of fish in sample, age i
N_i	=	estimated number of fish, age i, in the landings of any one size group

Details of the derivation of these formulae are given by Gulland (1966).

The variance decreases by $\frac{1}{n}$ as more fish ($= n$) are aged. But it increases as the number of age groups in each length stratum (p_i) increases. If there was only a single age group in a length stratum $p_i = 1$, $(1-p_i) = 0$ and the variance would be zero.

It is usual to try to make the variance in each length stratum equal so the answer to the question of 'how many fish in an age length key?' is as many as possible with the manpower available, the total number of otoliths being divided between strata on the basis of the number of age groups likely to be present in each stratum. This has to be determined for each species. In brief it means ageing more large fish, where age for length usually varies considerably, than smaller fish, where age and size are closely related.

4.13.3 Age-length keys for different gears

Different kinds of gear are often used in one fishery. For example, in the Danish sole fishery two kinds of gear are used, trawls with small meshes and set nets with larger meshes. Therefore, the landings from the set net fishery contain more big fish than the trawl landings. These differences are visible in Fig. 4.3. As it is complicated to obtain a sample which gives a representative picture of the length distribution of the total catch it is easier to distinguish between and keep the two sets of data apart. One age-length key can then be used separately with each set of length composition data and two sets of age compositions calculated. Also, if the fisheries with different gears take place on separate

parts of the same stock, for example, one fishery on young fish and another on the older fish, it is preferable to compile separate age-length keys for each fishery.

4.13.4 Age-length keys for each sex

Growth rates of male and female fish of the same species may differ; for example, if the females are growing faster than the males a three-year-old female could be bigger than a male of the same age. Handling the two sexes together in the age-length key can give unwanted complications. It is, therefore, necessary to separate the two sexes in constructing age-length keys. It is not always possible to sex commercially-landed fish so this method is not always usable because the method also requires length compositions by sex.

4.13.5 Frequency of construction of age-length keys

As fish grow during a year how often should age-length keys be compiled if they are to be valid? For slow-growing fish (less than 10 cm a year) annual age-length keys are used but for faster-growing fish it is necessary to use keys compiled over shorter periods. Table 4.5 shows an example for North Sea cod.

Table 4.5. Cod, North Sea, 1960. Quarterly age-length keys

I. Quarter							III. Quarter						
Length Group cm	I	II	III	IV	V	Total	Length Group cm	I	II	III	IV	V	Total
30-39		36	1			37	30-39	12	36				48
40-49		62	4			66	40-49	1	73	3			77
50-59		15	18	2		35	50-59	1	54	6			61
60-69			19	1	1	21	60-69		13	25			38
70-79			4	20	9	33	70-79			27	7		34
II. Quarter							**IV. Quarter**						
Length Group cm	I	II	III	IV	V	Total	Length Group cm	I	II	III	IV	V	Total
30-39		26	4			30	30-39	56	8				64
40-49		51	1			52	40-49	23	50	2			75
50-59		41	9			50	50-59		63	2			65
60-69		2	21	3	1	27	60-69		43	17	11		71
70-79			28	7		35	70-79			30	6		36

The smaller (and younger) sizes in particular show large changes in abundance during the year. In the first quarter the number of fish in the 30-39 cm length group is 37 and in the fourth quarter the number has increased to 64. During the year fish smaller than 30 cm have grown and have successively entered the 30 cm length group. most of the change in the distribution is due to the entrance of one-year-old fish in the last two quarters.

A single age-length key would give a biased age composition especially if there was a difference in the number of fish landed in each quarter. In this instance it is better to use the quarterly age-length keys with the respective quarterly landings.

4.14 Publishing Stock Record Data

Very often several countries carry out research on the same species and to facilitate cooperation and to ensure that only the most important and useful results of such investigations which are published standard tables are indispensable.

An example has already been given in section 3 (Appendix 5) for length composition data; this also includes age composition data.

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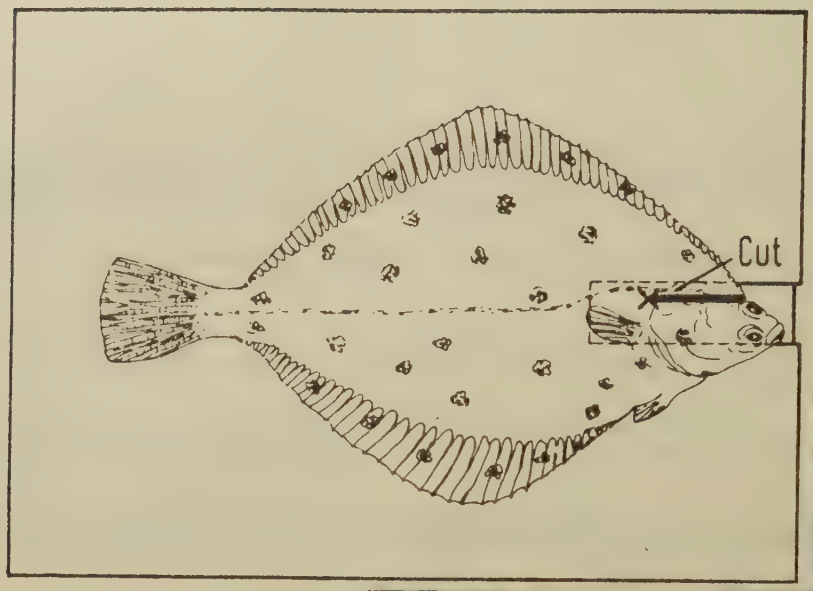


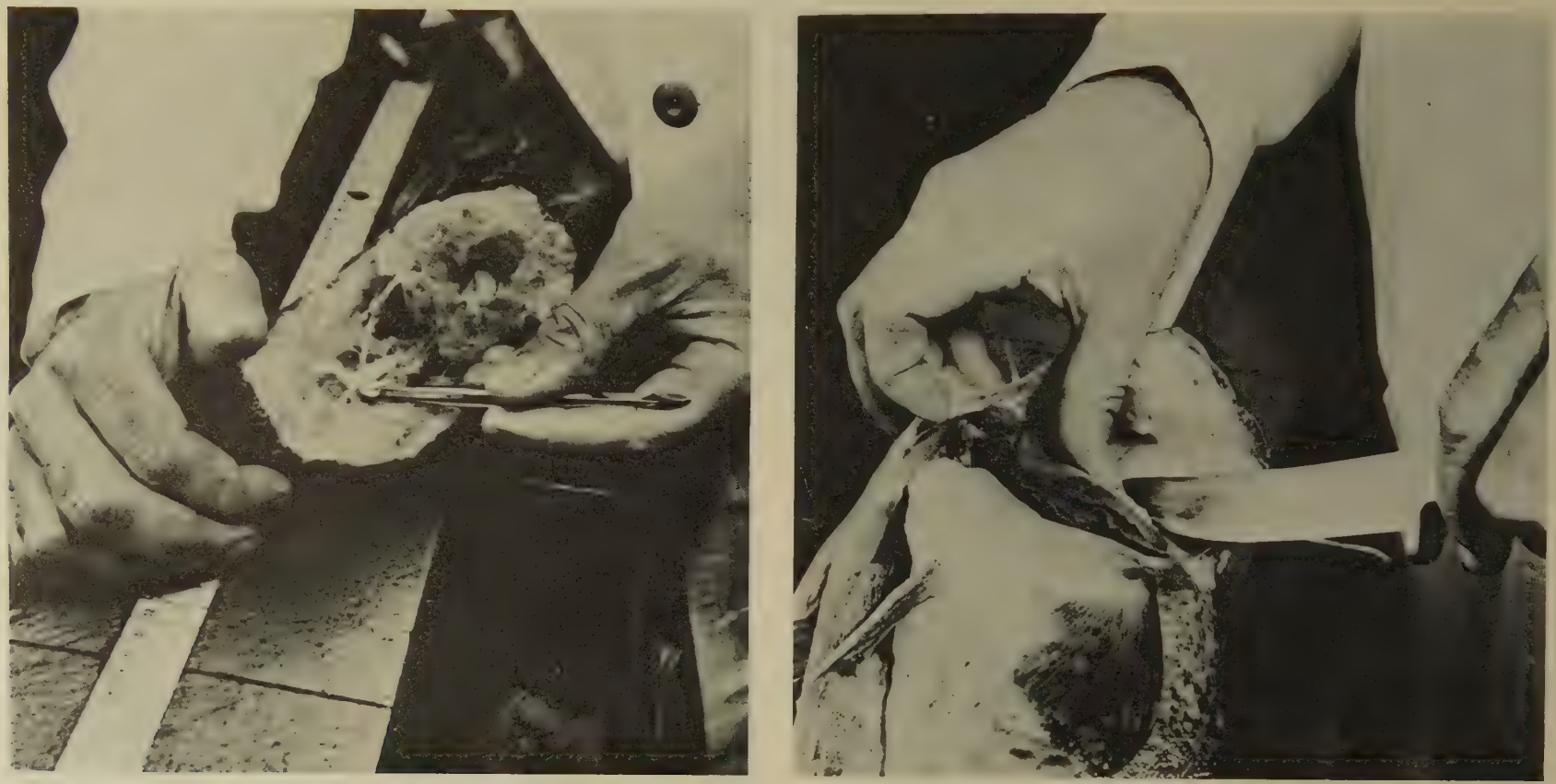
(a)

(b)

(c)

Fig. 4.1 Removal of otoliths from flatfish.

Fig. 4.2 Removal of otoliths from roundfish.



(a) (b)

Fig. 4.3 Alternative methods of removing otoliths from roundfish: (a) by lifting off the top of the skull; (b) by extracting them from under the gills.

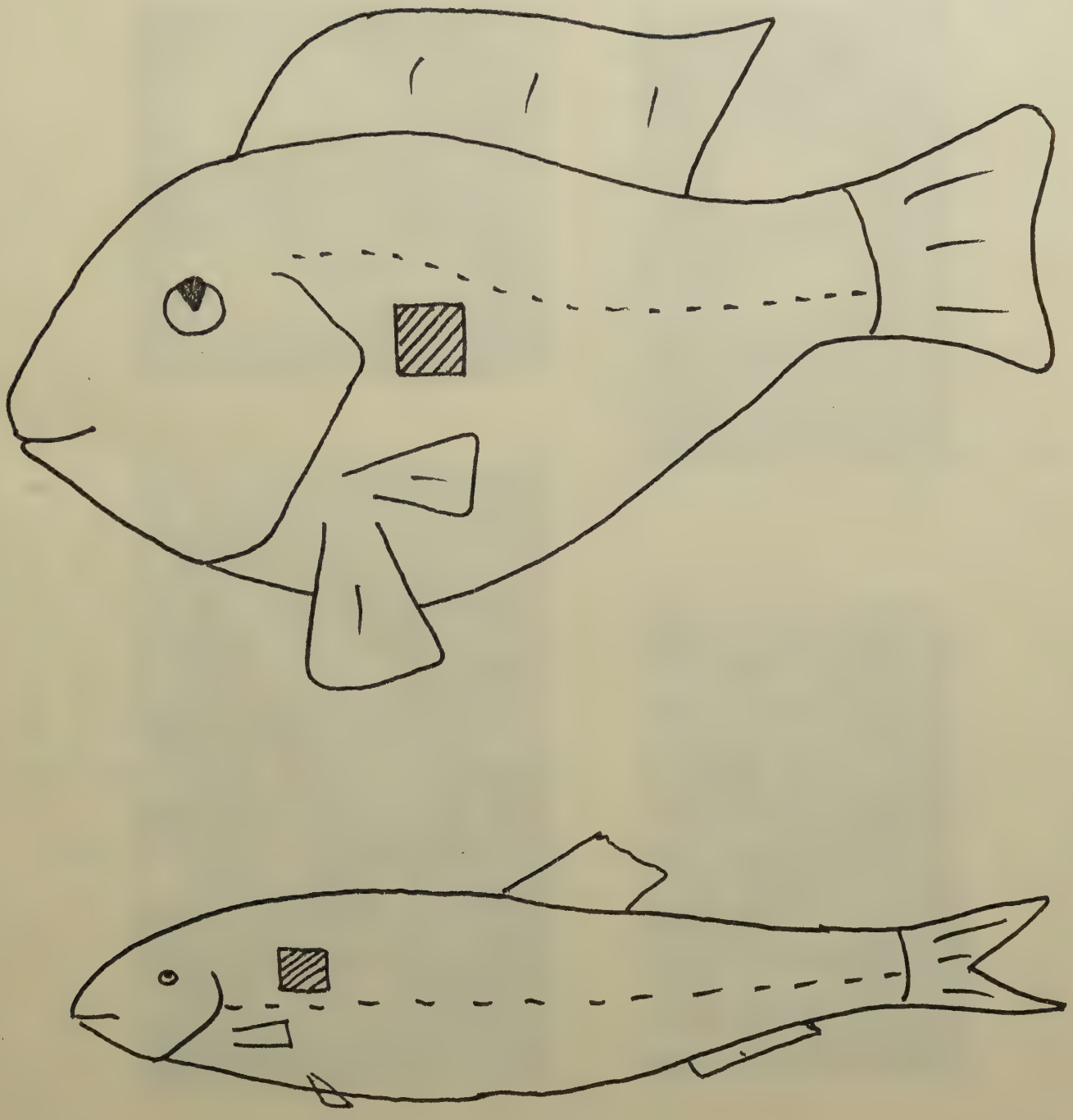
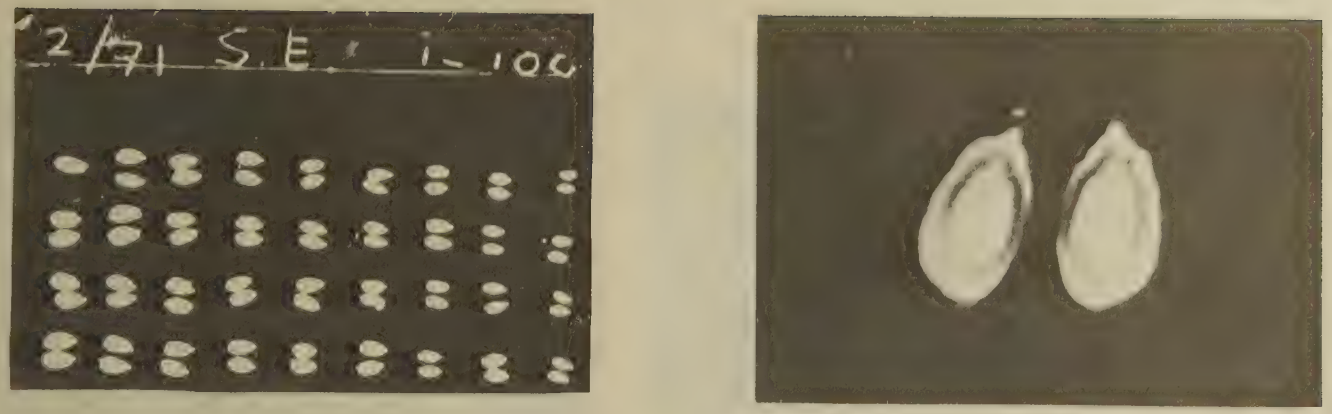
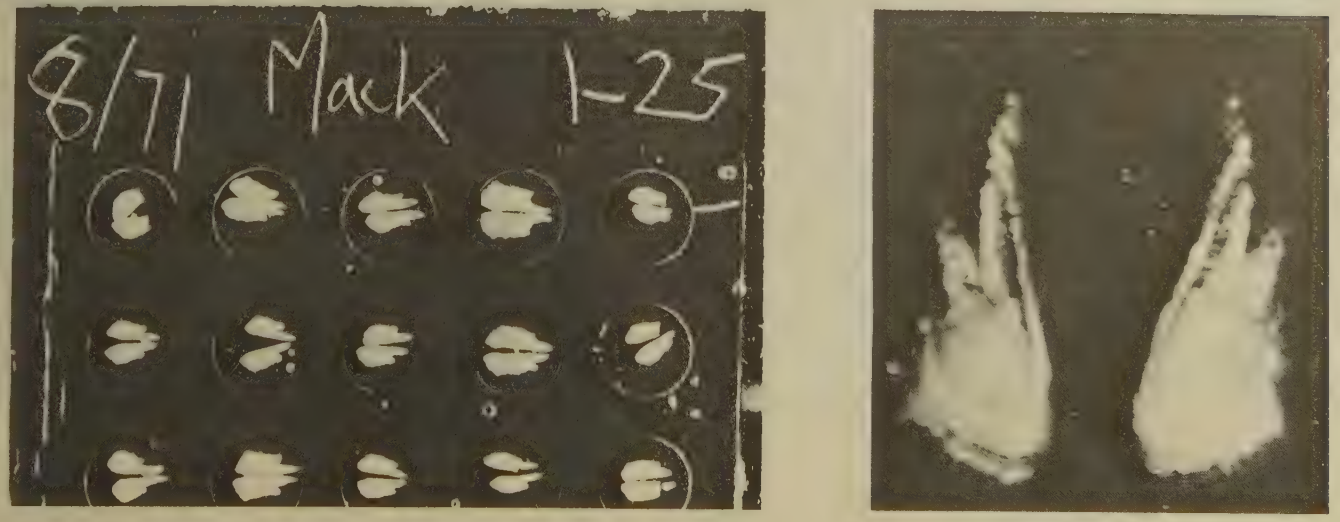


Fig. 4.4. Hatched areas show the best positions for taking scales



Sand eel



Weel eel

Fig. 4.5 Storage of small otoliths by mounting them on a microscope slide.

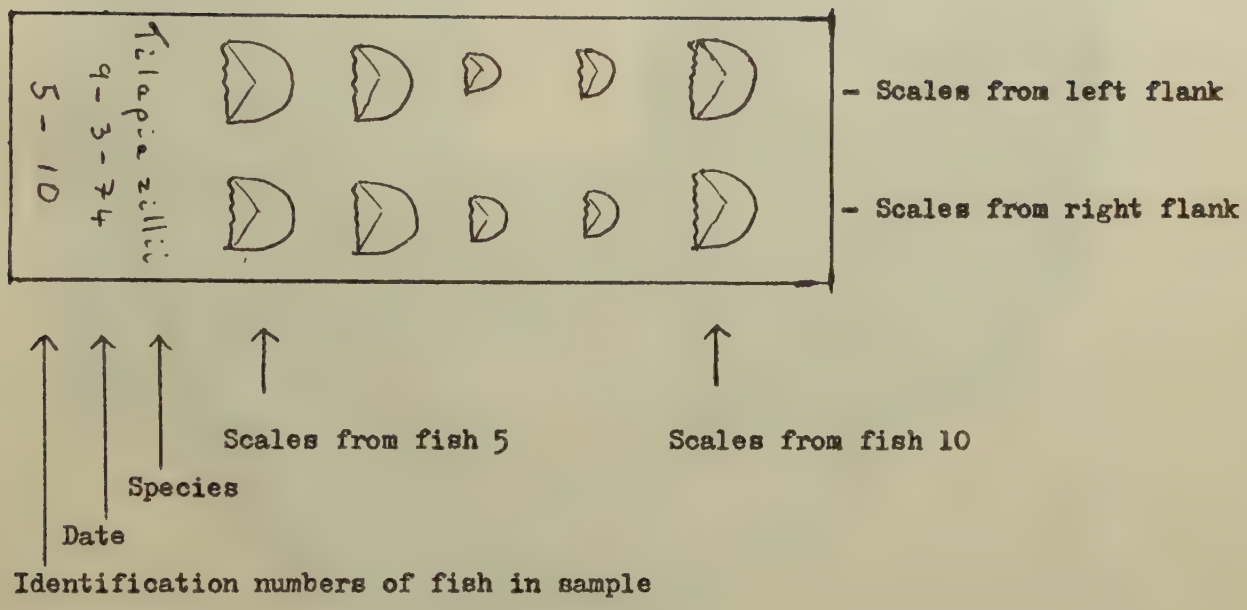
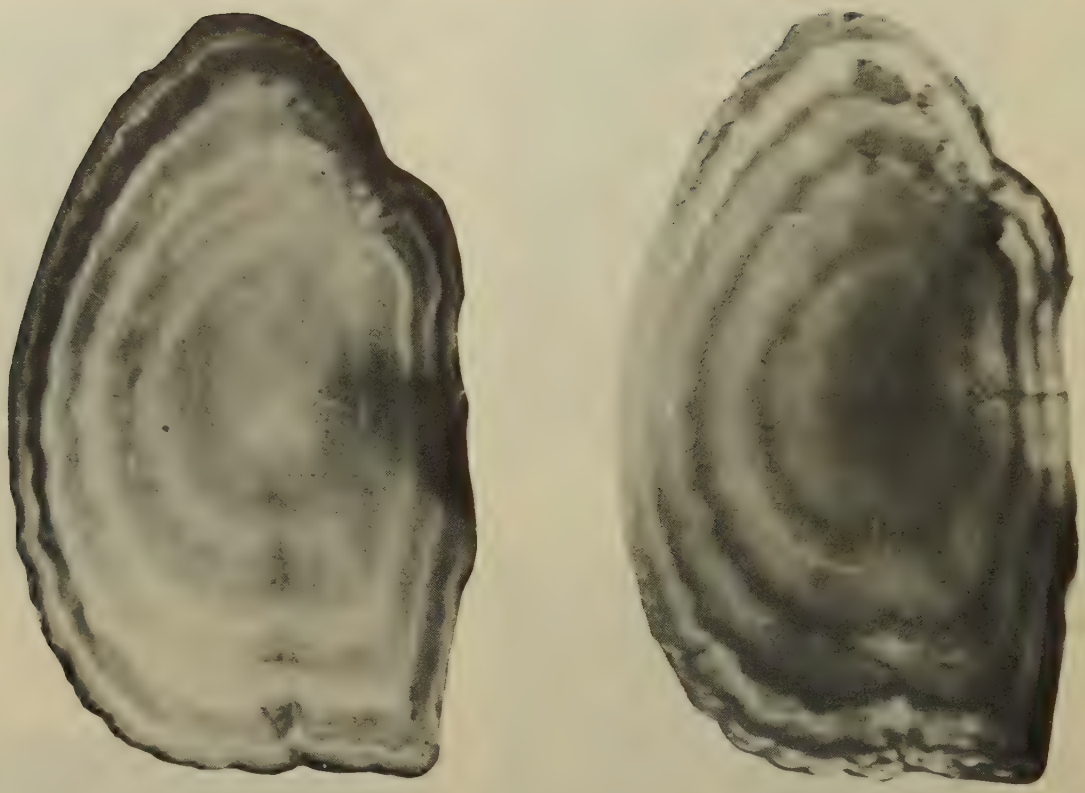


Fig. 4.6 Method of mounting scales on a glass slide



Illuminated from above
viewed against a dark background
(a)

Illuminated from below
by transmitted light
(b)

Fig. 4.7 An otolith viewed by two different methods.

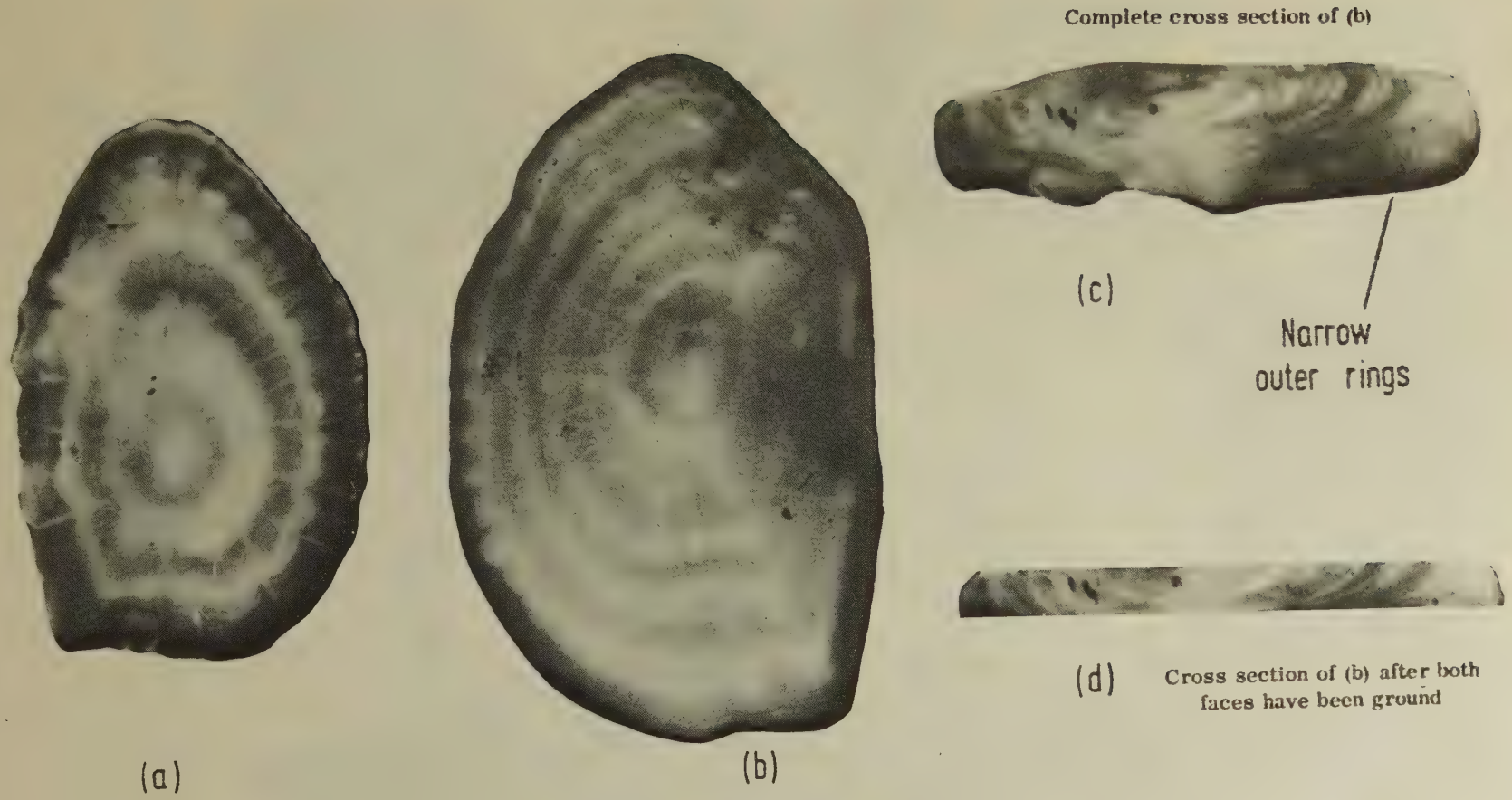


Fig. 4.8 Plaice otoliths: (a) a thin otolith from a young fish, (b) a thick otolith from an old fish.

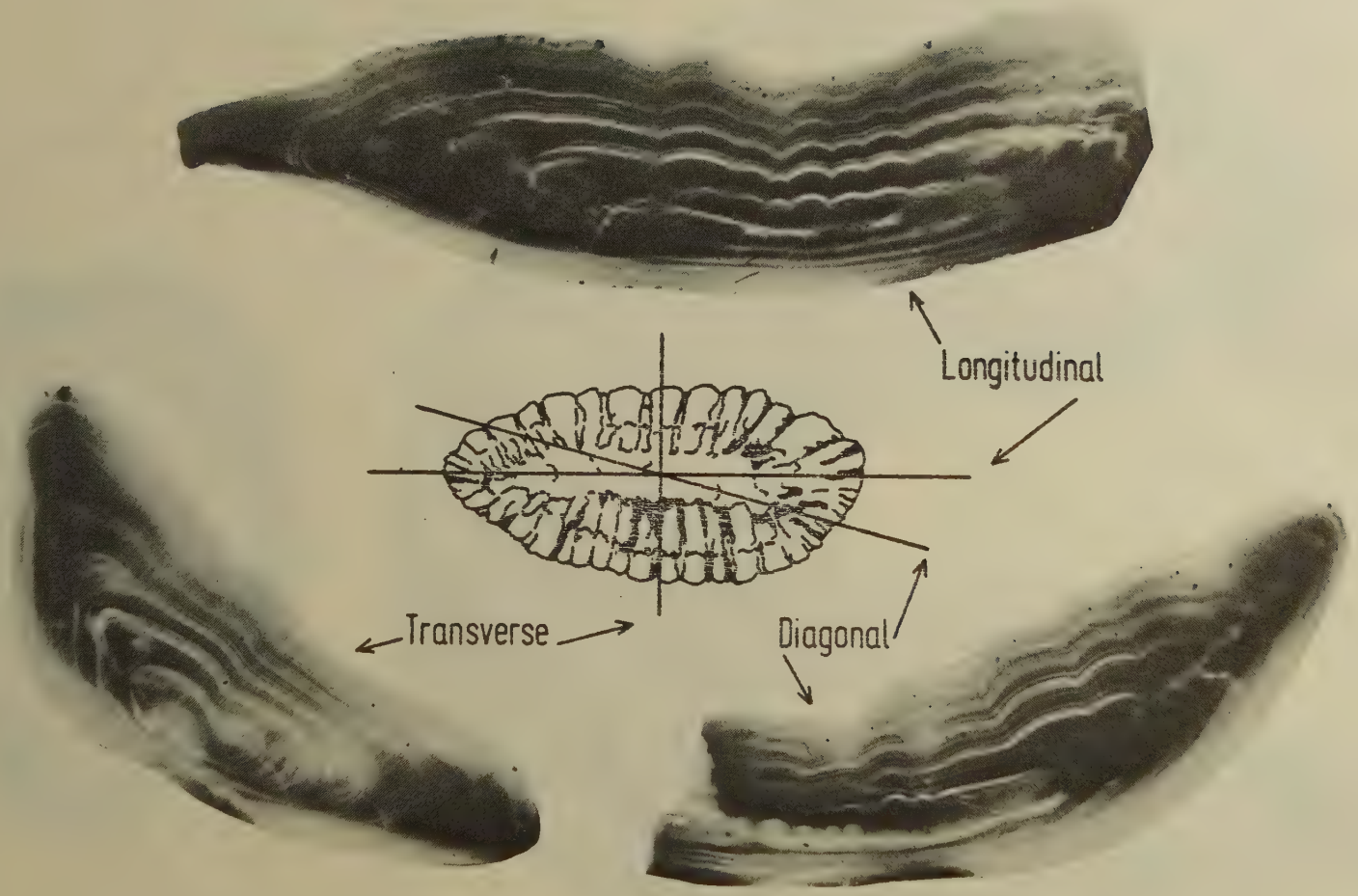


Fig. 4.9 A series of cross sections taken through a cod otolith.

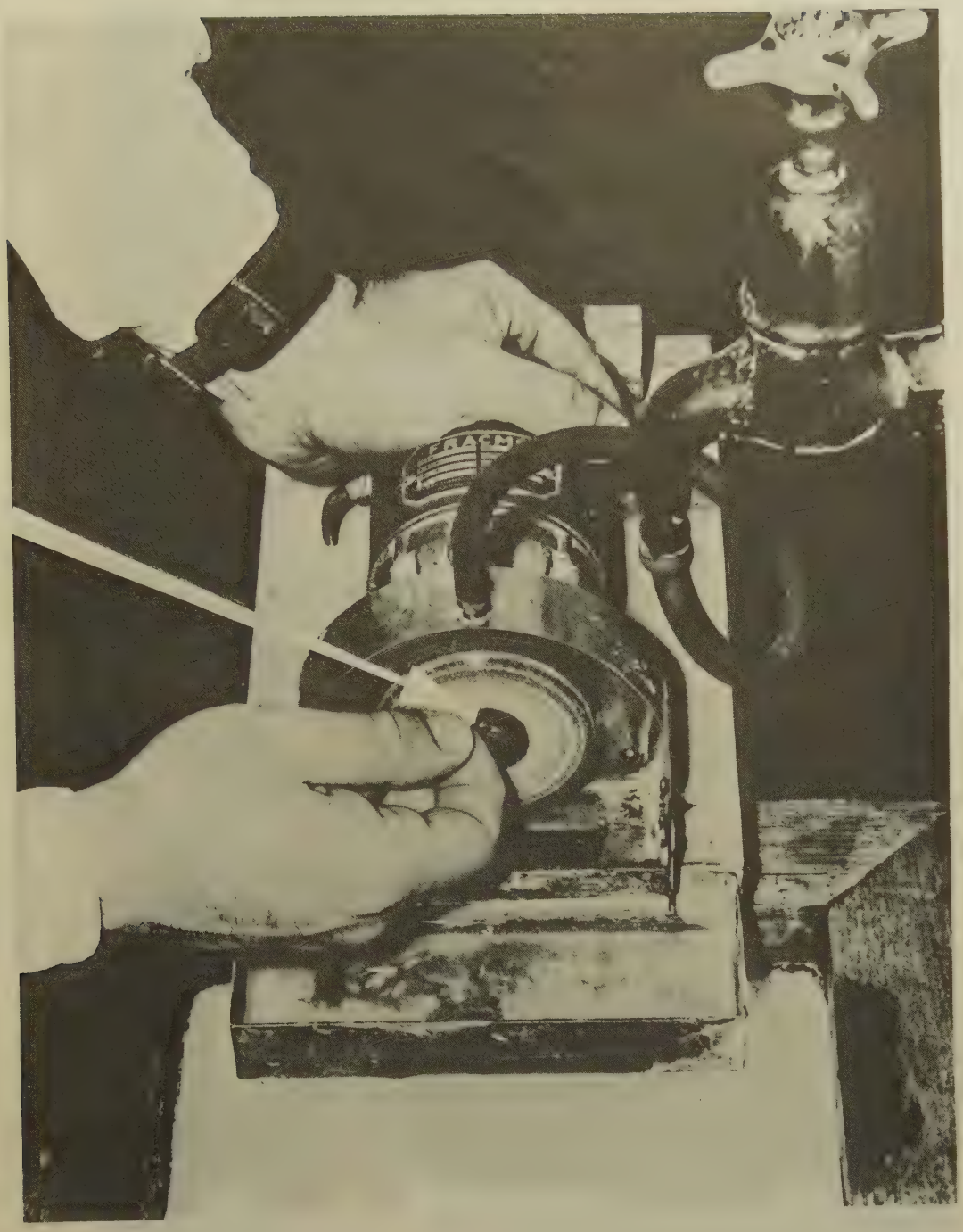
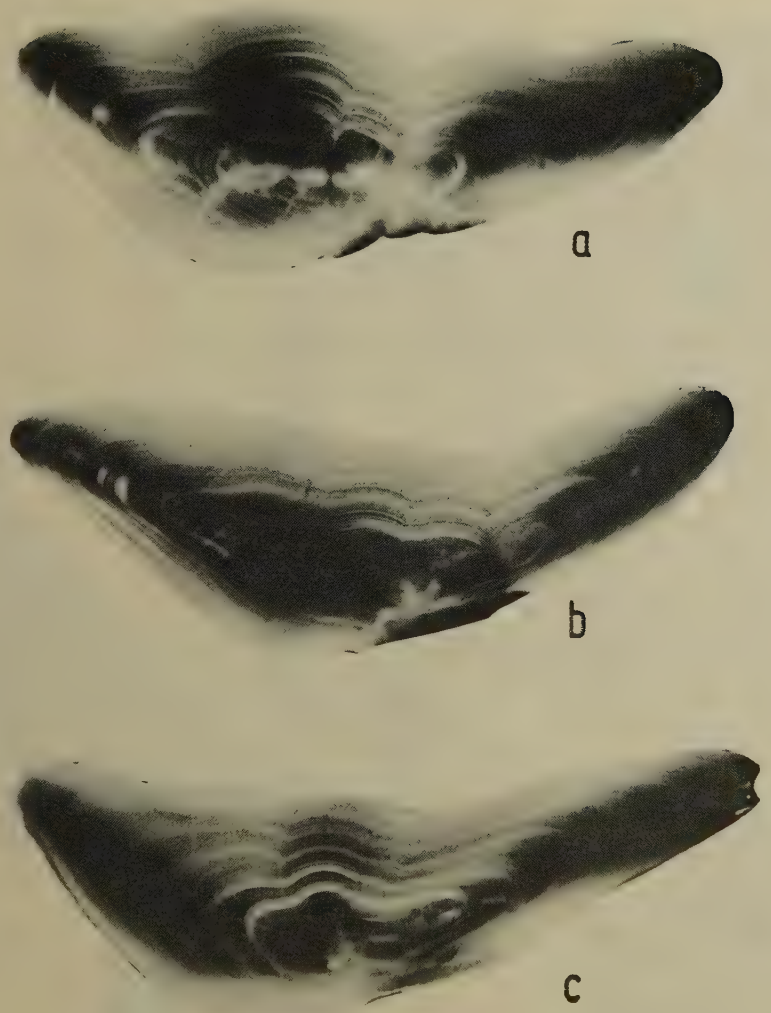


Fig. 4.10 A grinding machine for preparing otolith sections.



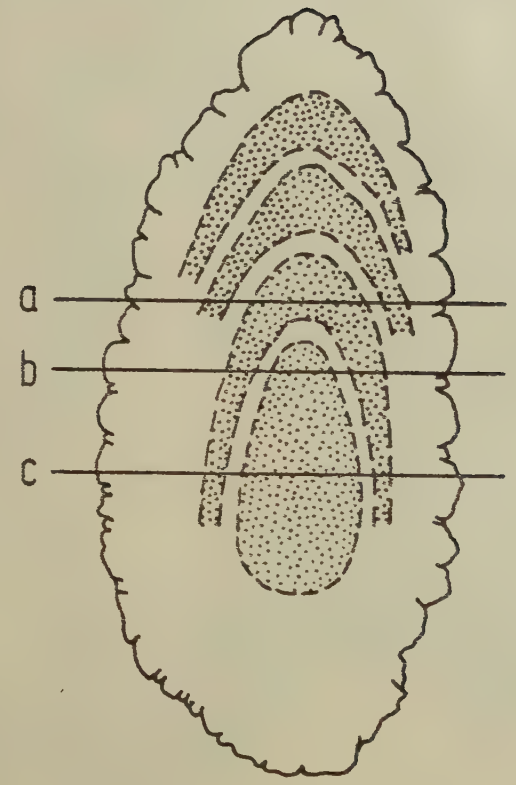
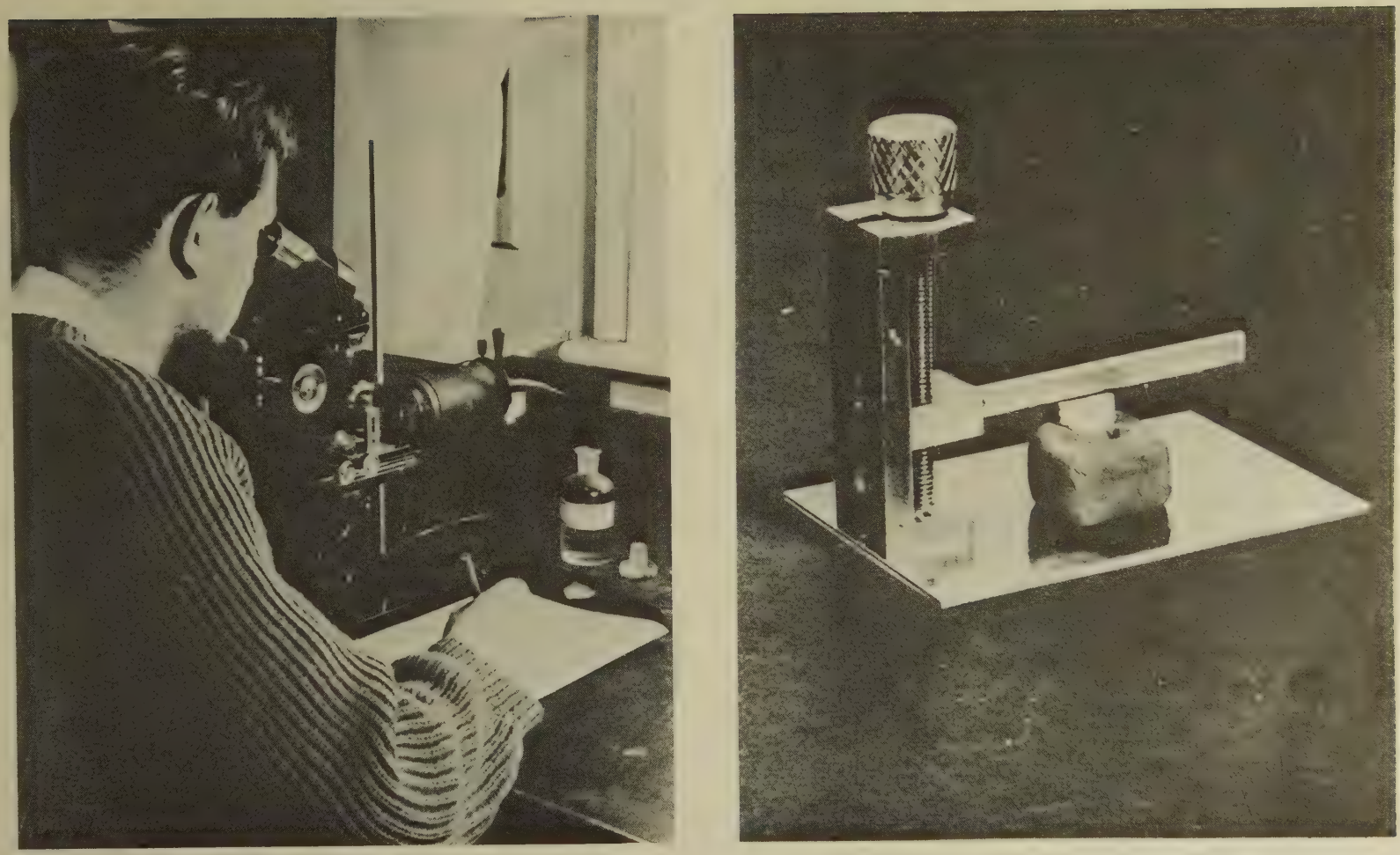


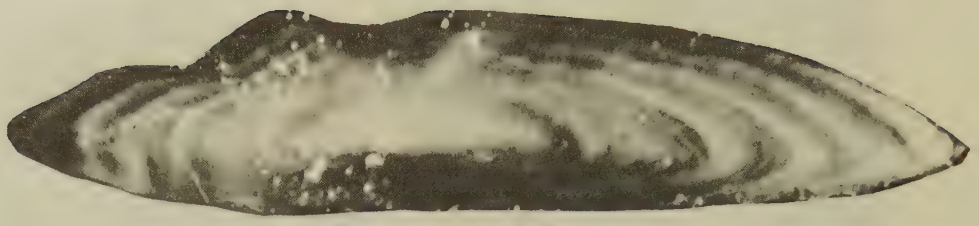
Fig. 4.11 Three transverse sections taken at various points through the same otolith.



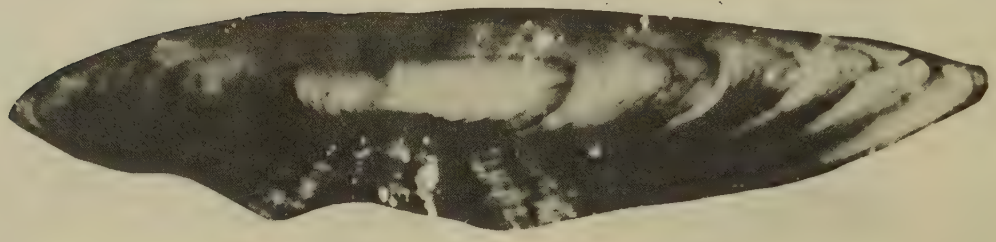
(a) (b)

Fig. 4.12 Method of mounting and illuminating the cross section of a cod otolith.

North Sea Plaice

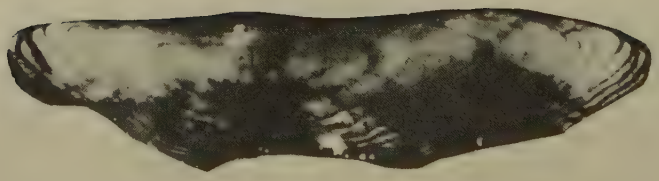


unburned cross section



after burning

North Sea Sole



after burning

Fig. 4.13

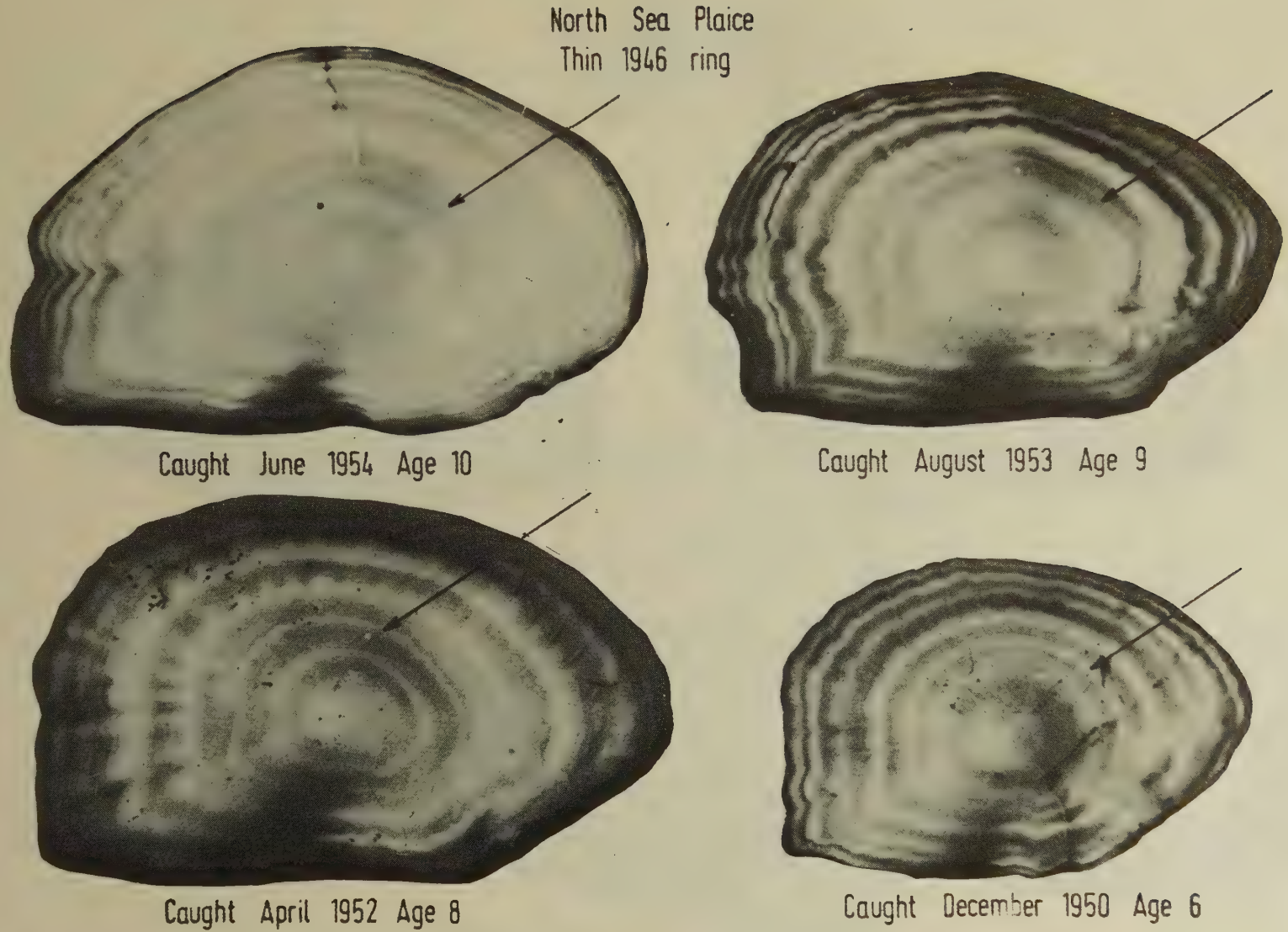

North Sea Plaice
Thin 1946 ring
Caught June 1954 Age 10
Caught August 1953 Age 9
Caught April 1952 Age 8
Caught December 1950 Age 6

Fig. 4.14

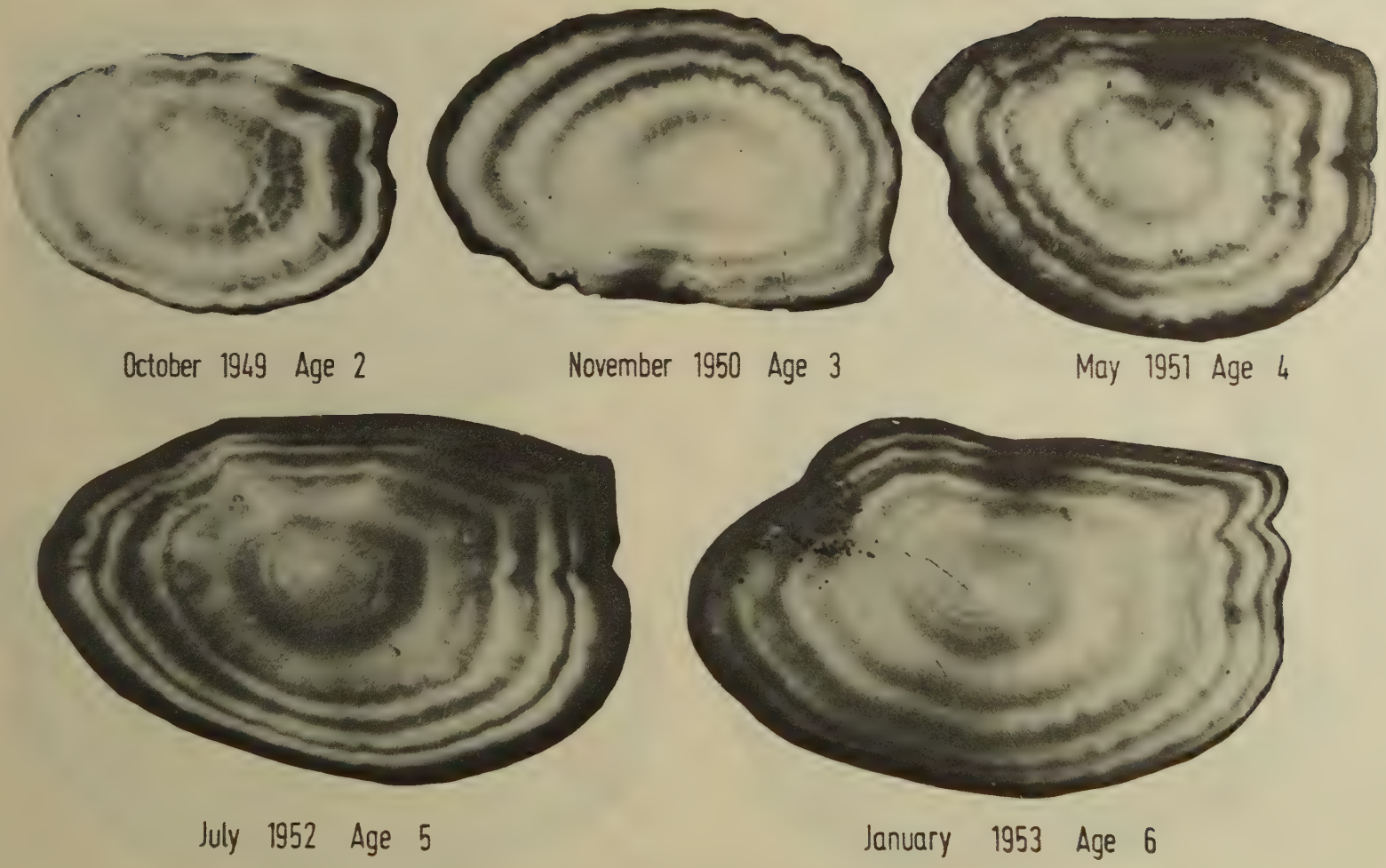
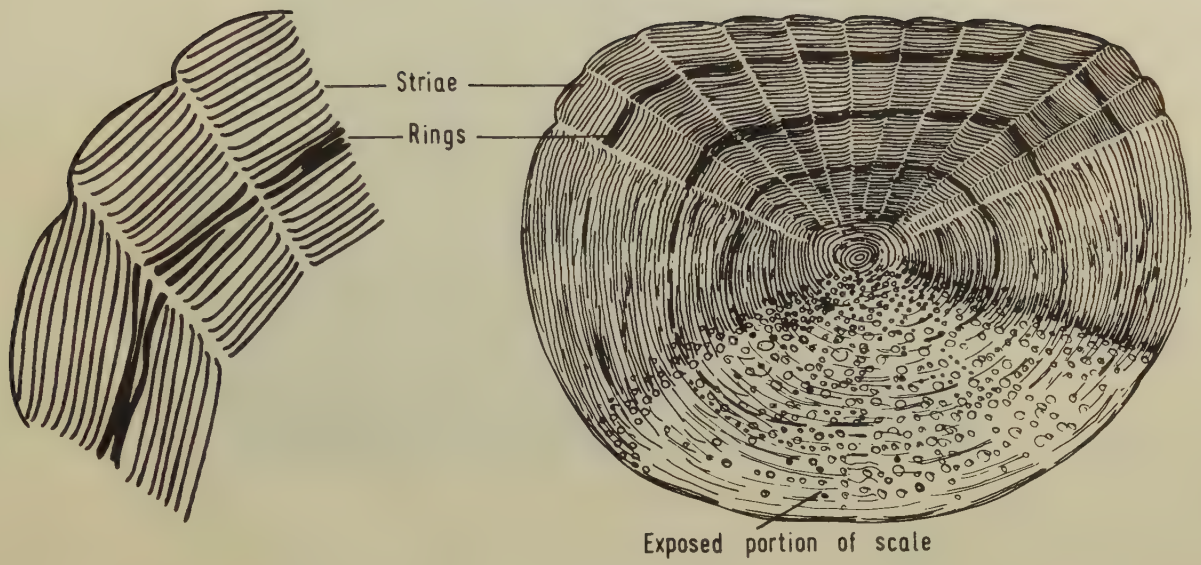


Fig. 4.15 Plaice otoliths, all with a similar nucleus.



Scale of Tilapia galilaea

Fig. 4.16

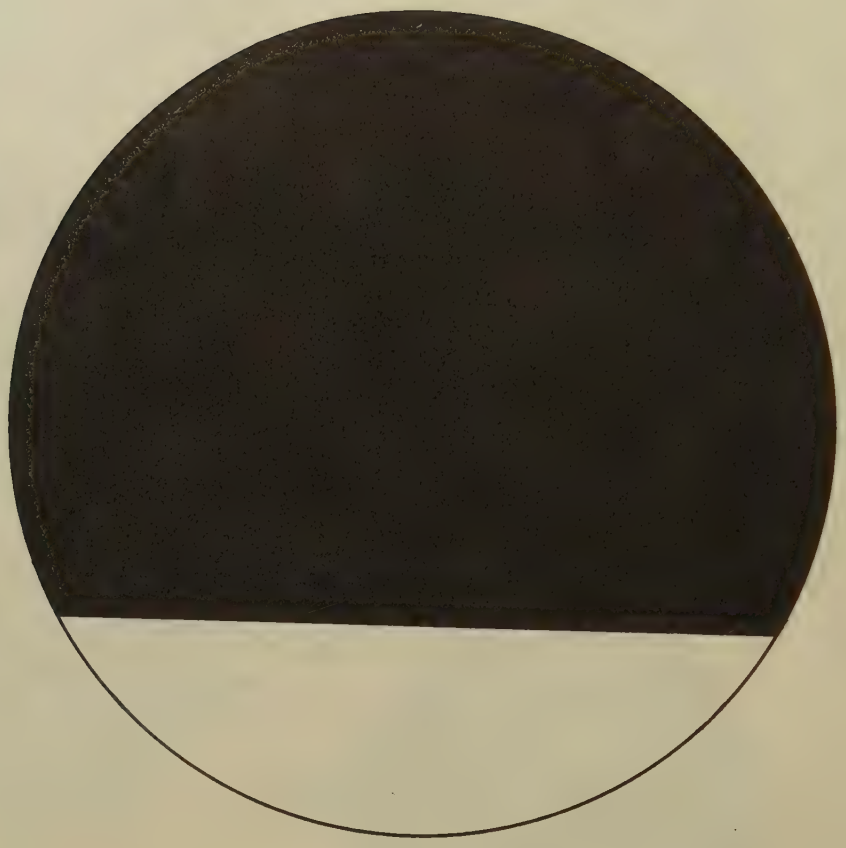


Fig. 4.17 The lighting of the microscope field for scale examination.

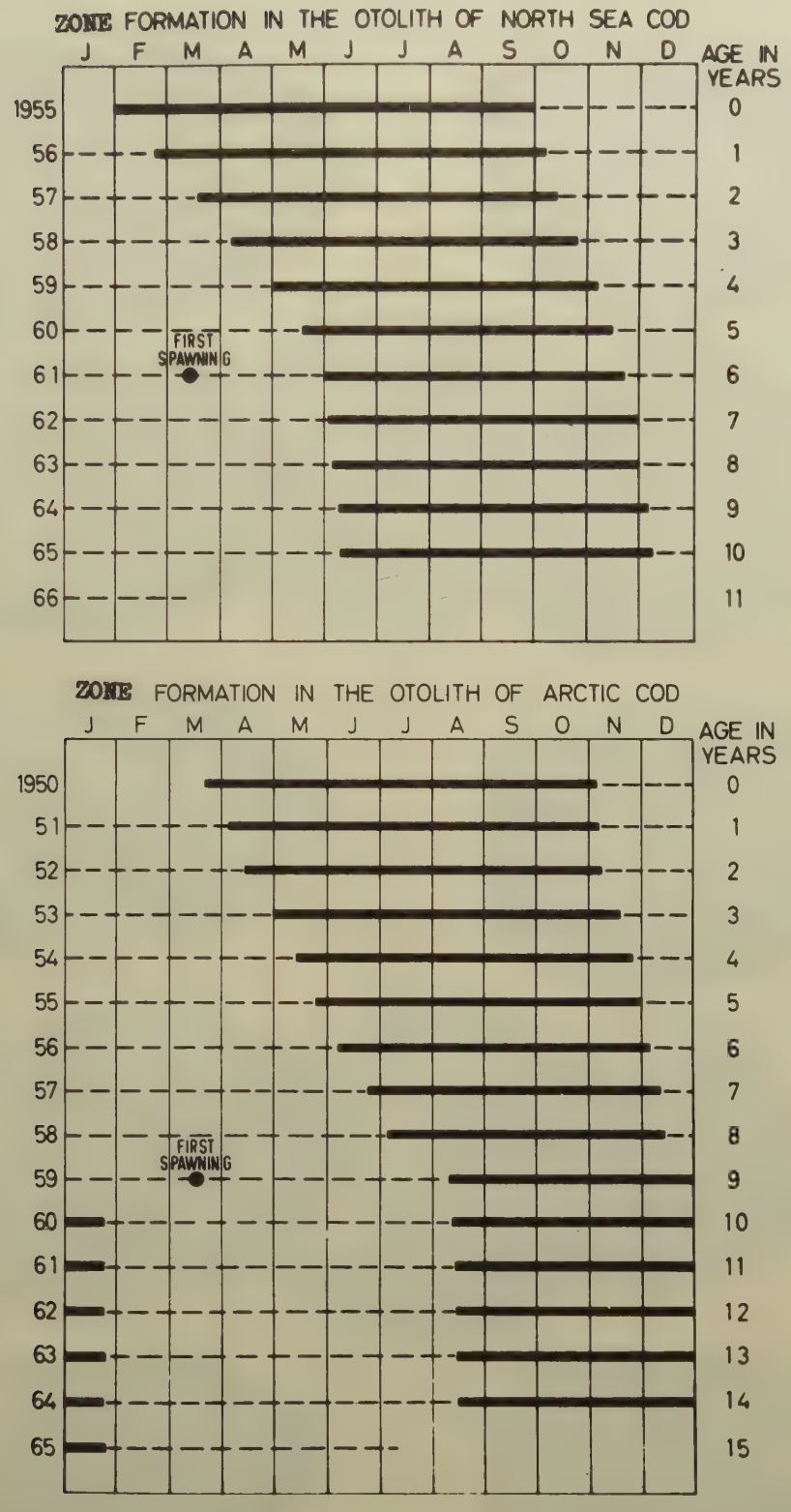
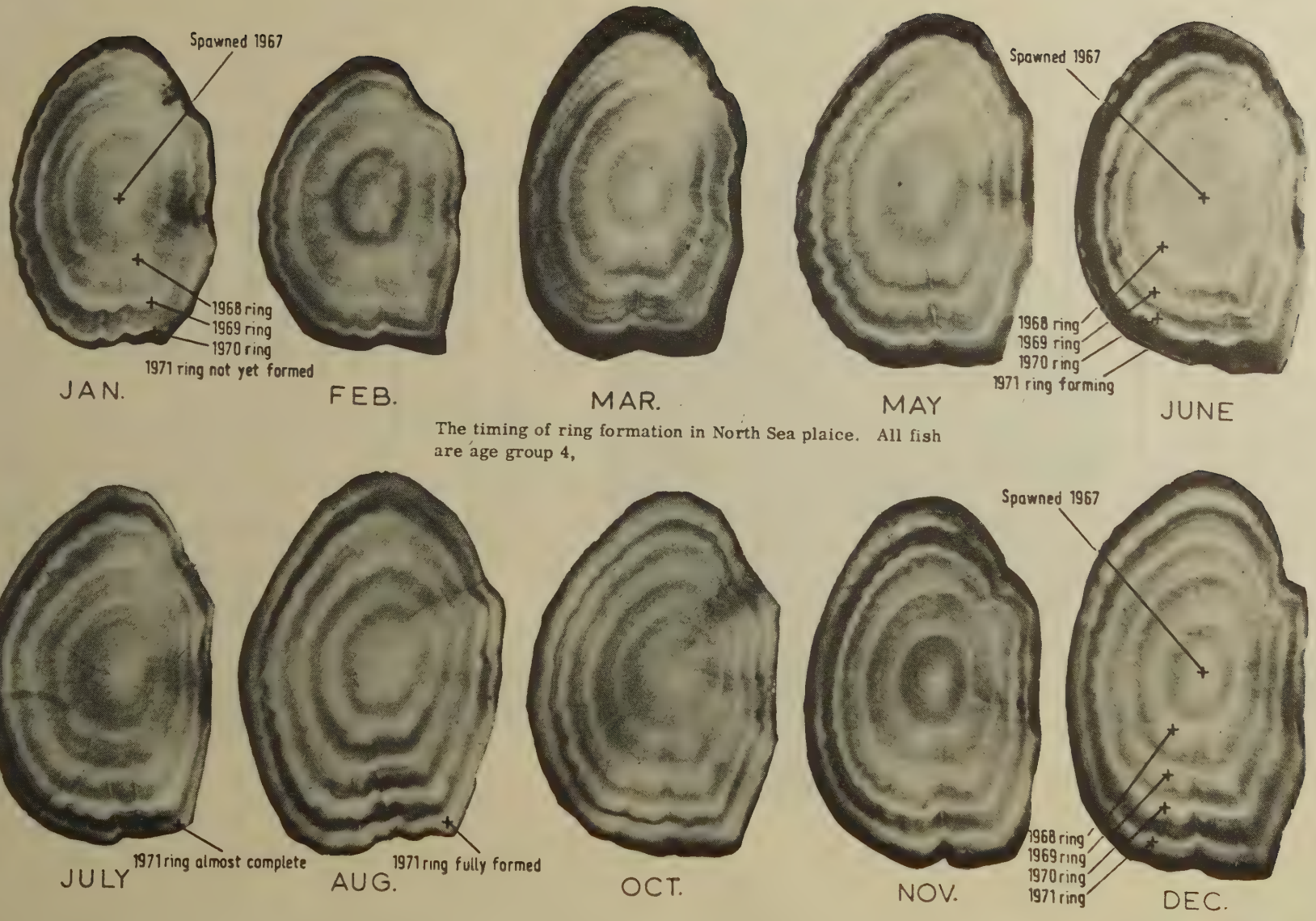


Fig. 4.18 Zone formation of the otoliths of North Sea cod (upper graph) and Arctic cod (lower graph)

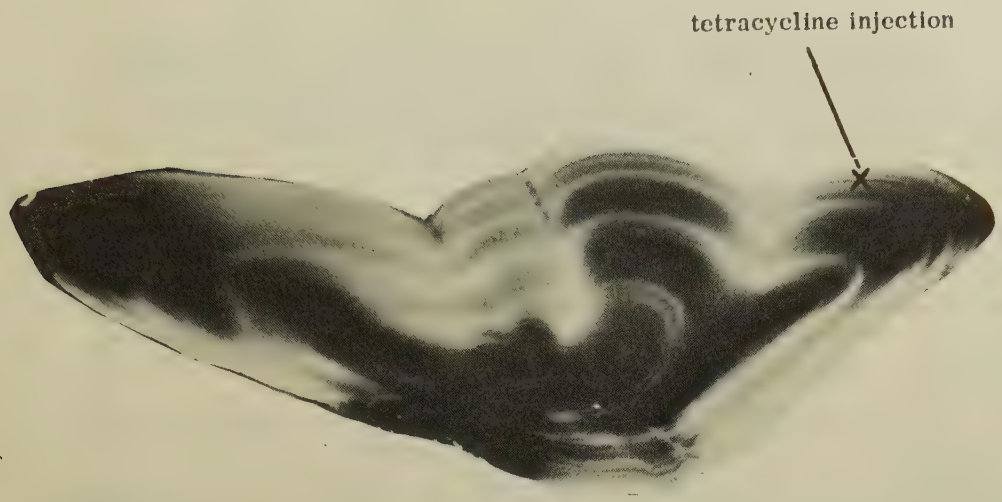
■ opaque - - - hyaline



The timing of ring formation in North Sea plaice. All fish are age group 4,

Fig. 4.19

WEST OF SCOTLAND COD



Illuminated by normal transmitted light

Illuminated from above by ultra-violet light

Fig. 4.20 Otoliths of a west of Scotland cod, released after tagging and injection of tetracycline, June 1968; recaptured July 1969.

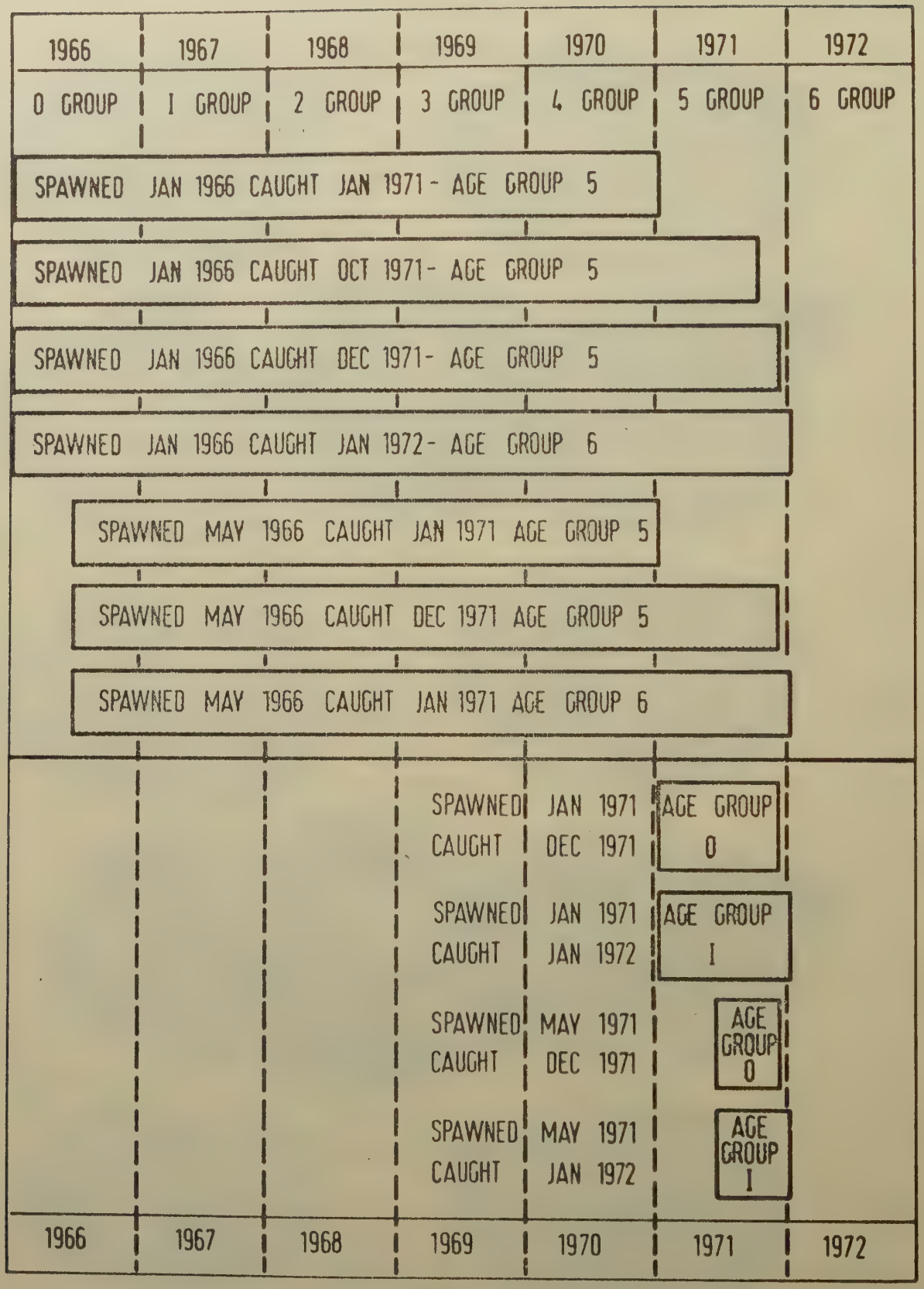


Fig. 4.21 The age of fish, taking 1 January as the birthday.

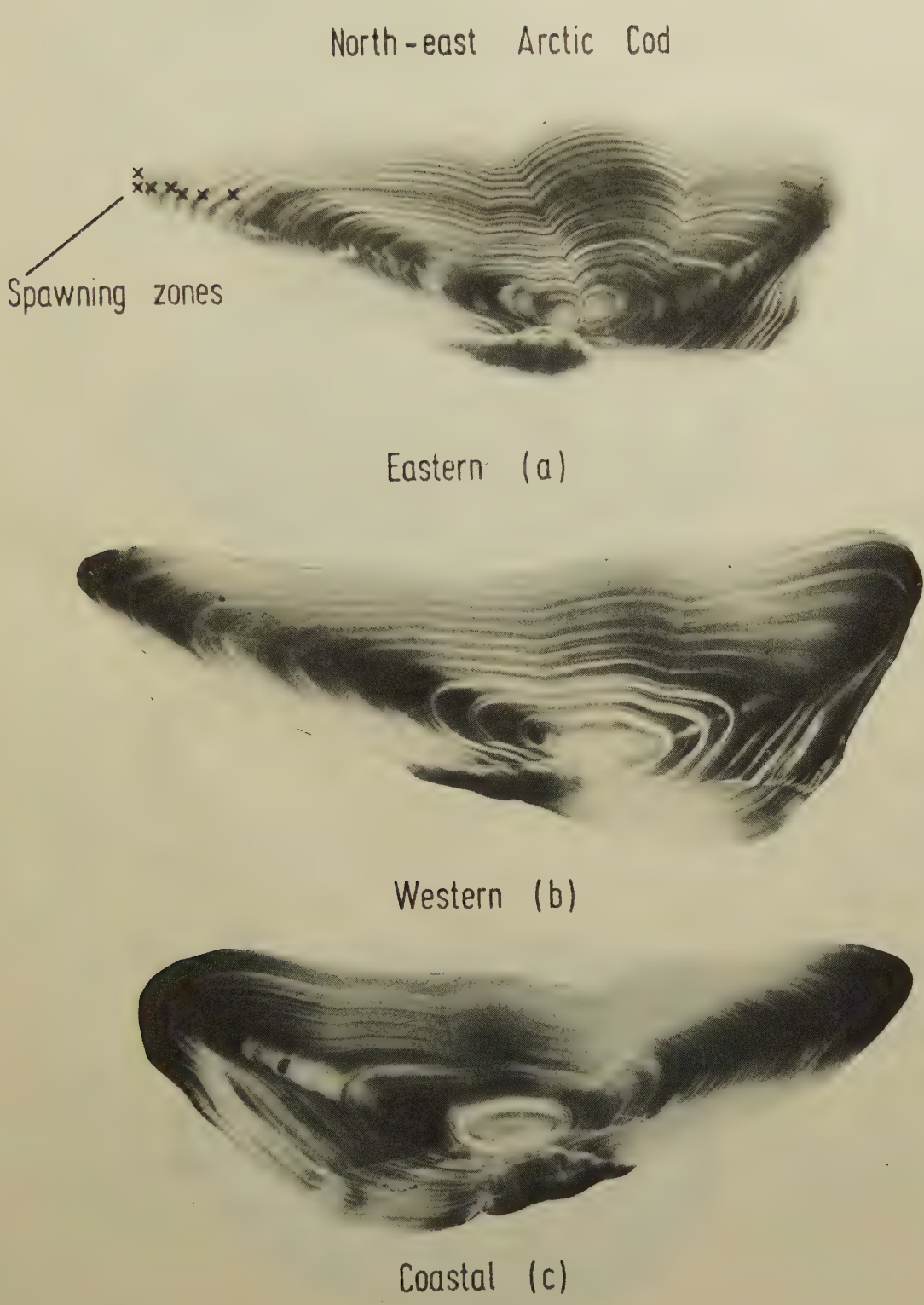


Fig. 4.22 Typical north-east Arctic cod otolith types.

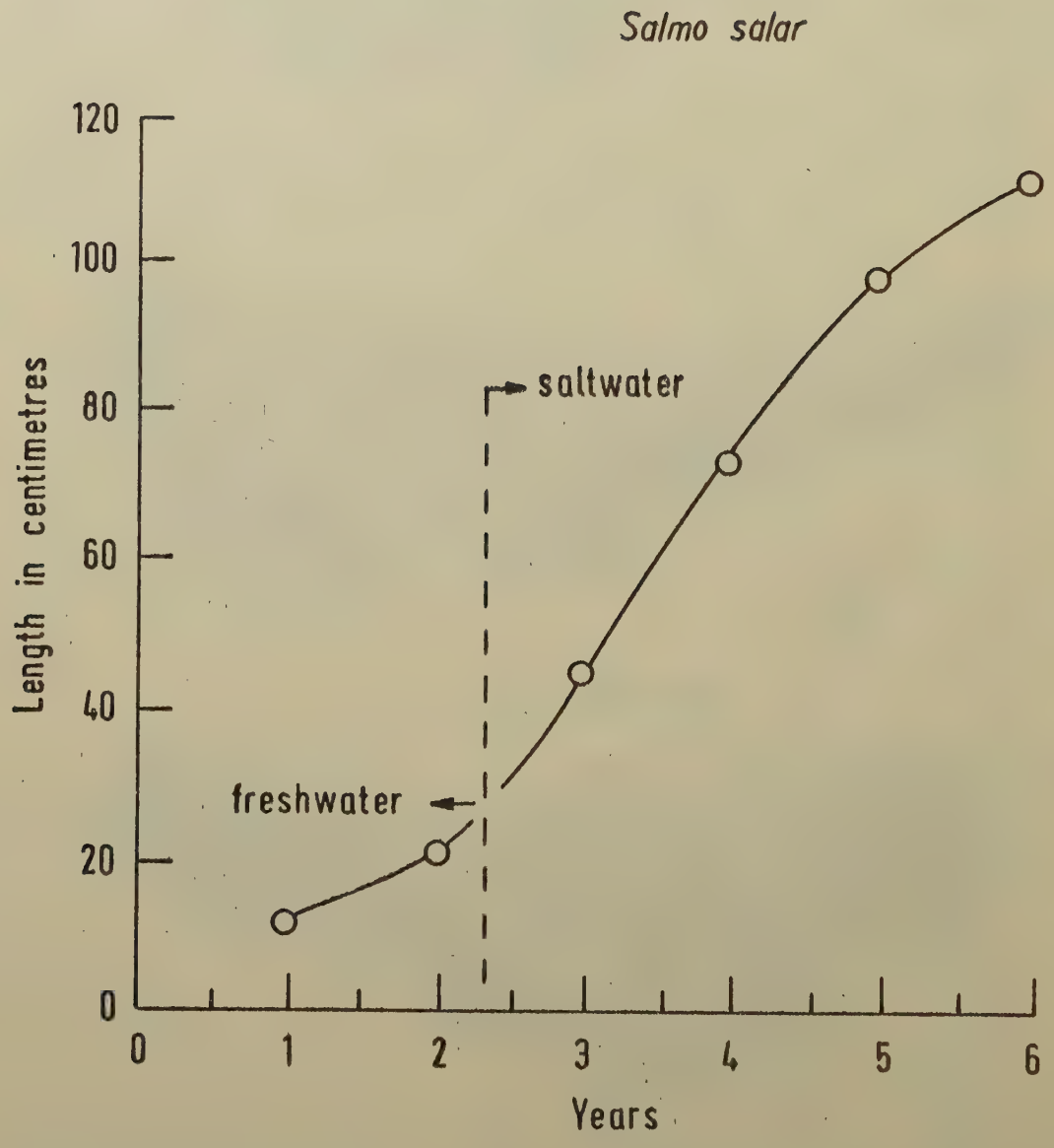


Fig. 4.23 · Growth curve for salmon.

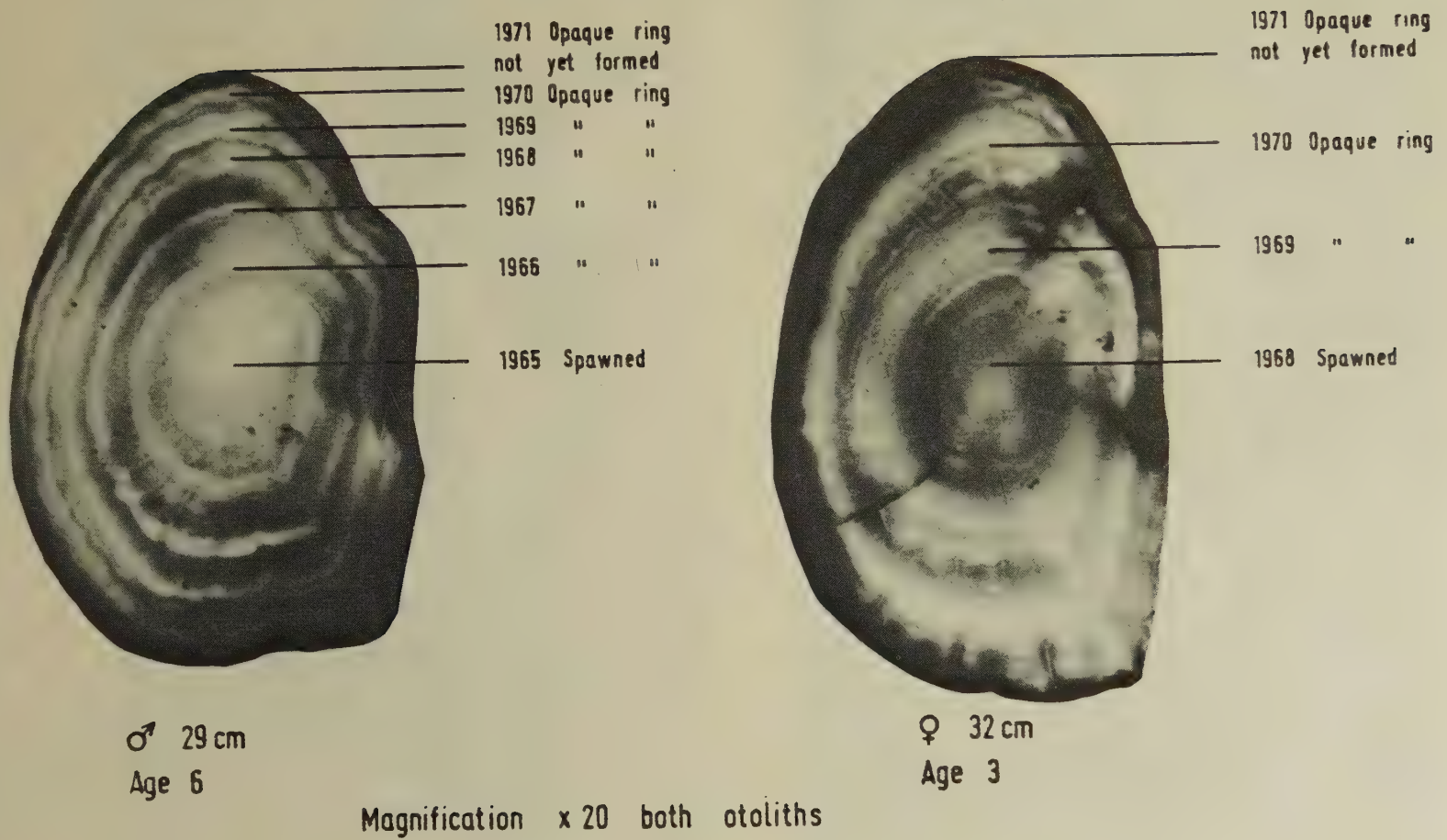


Fig. 4.24 Plaice otoliths from similar sized fish.

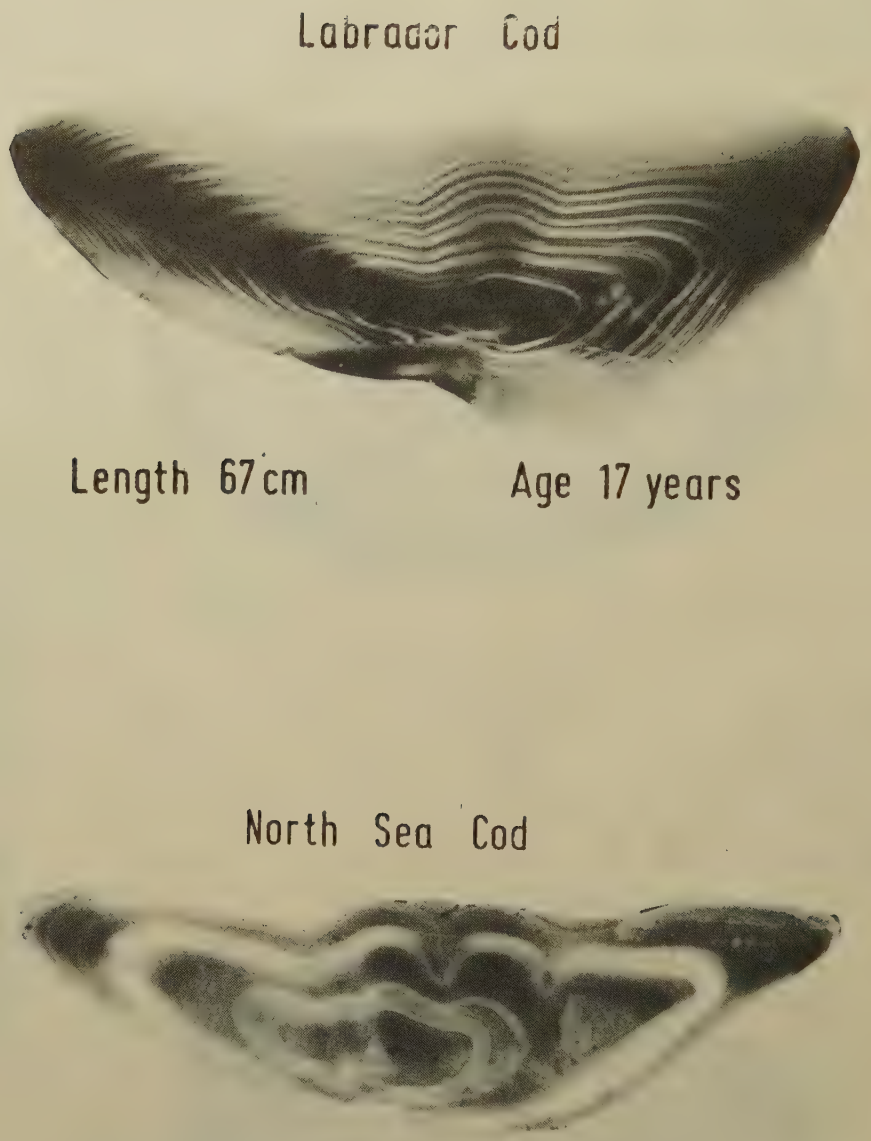


Fig. 4.25 Two cod otoliths from fish of the same size but widely differing age.

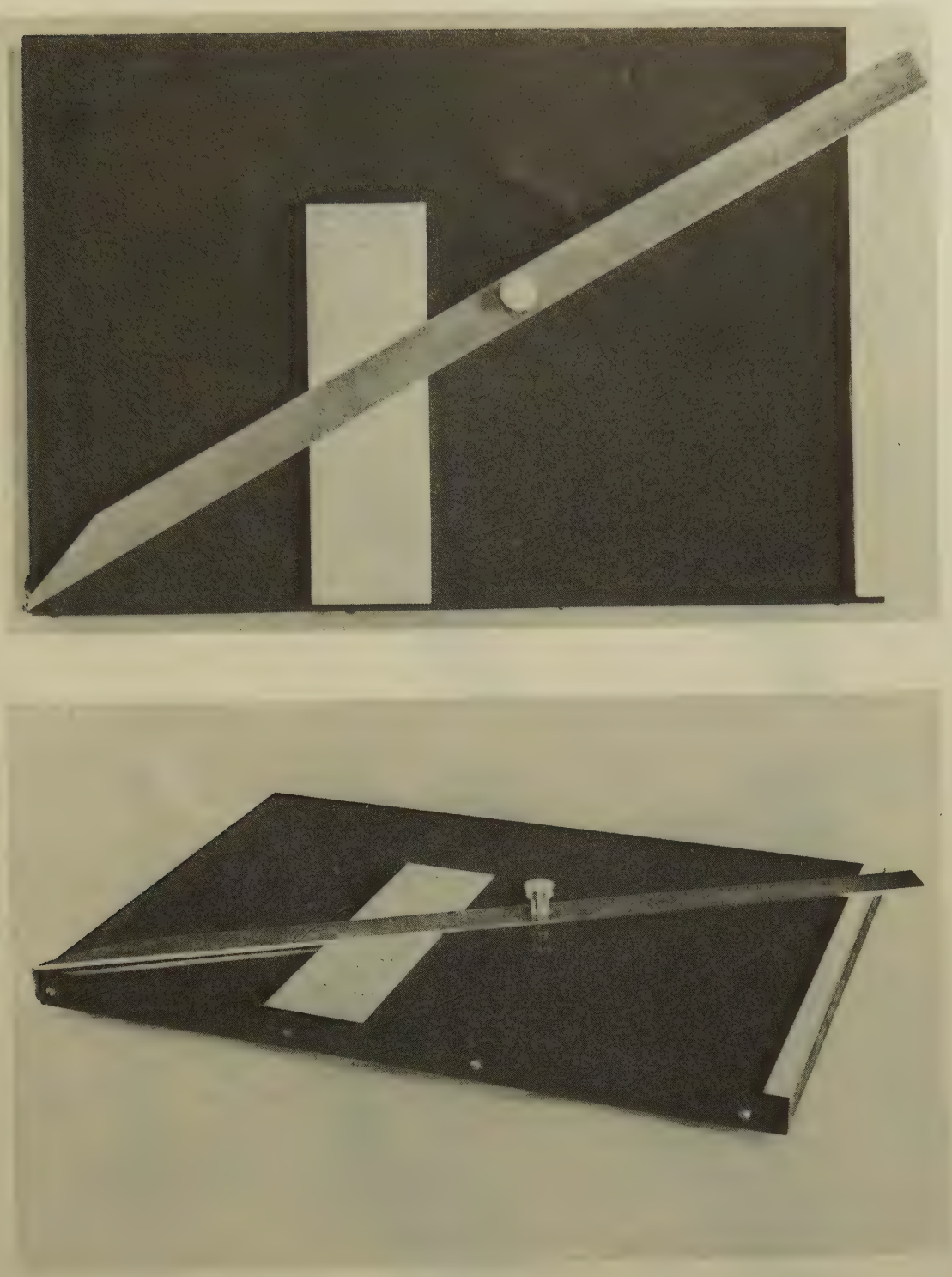


Fig. 4.28 A proportioning board.

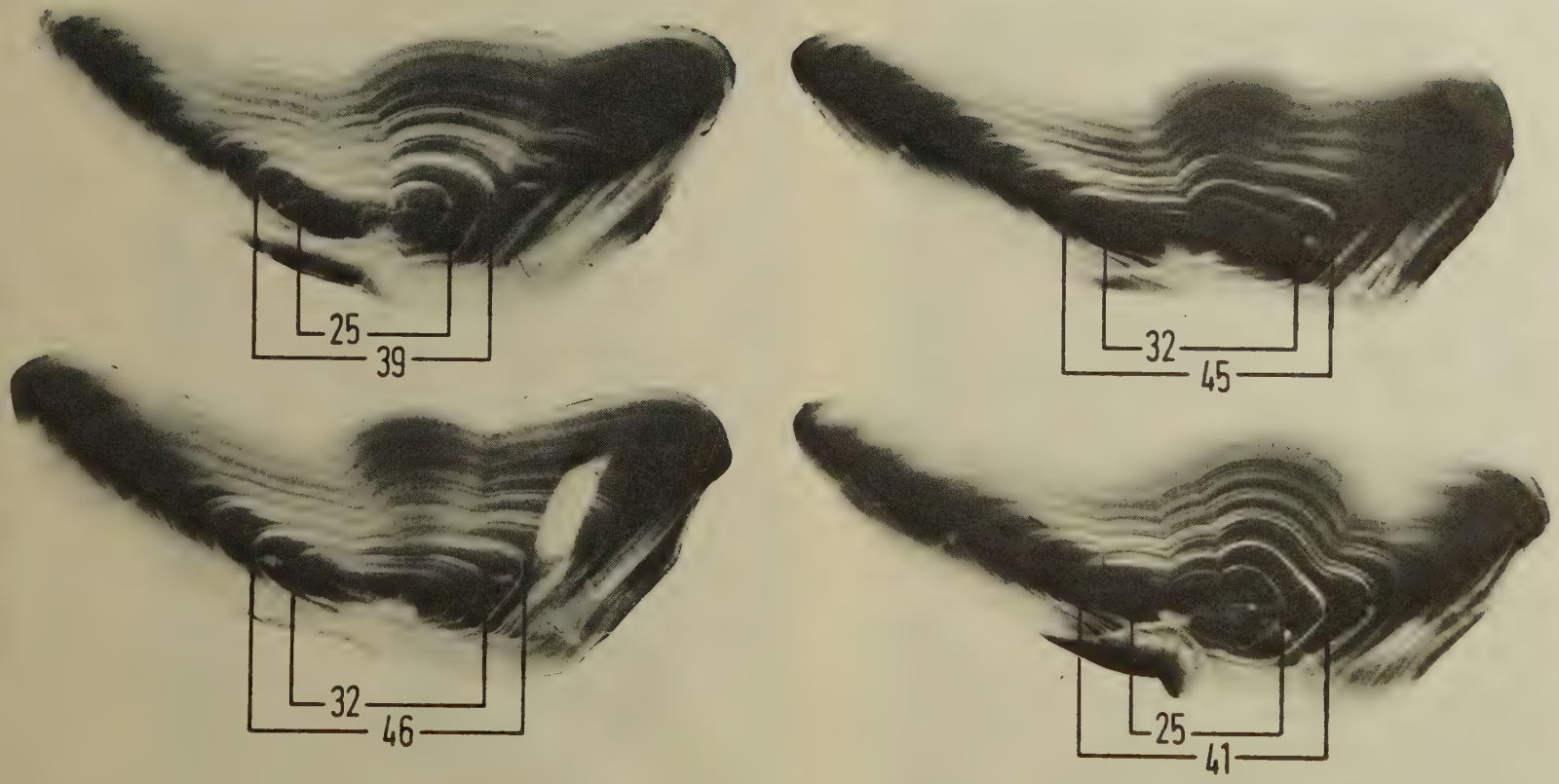


Fig. 4.29 A series of transverse sections taken through the nucleus of the same otolith

5. SEX, MATURITY AND FECUNDITY

5.1 Introduction

The determination of the sex ratio and of the sequence of changes in maturity stage during the year are of considerable importance in building a thorough knowledge of the general biology of an exploited stock. These form part of the basis of stock assessment. For some species it may be necessary to maintain routine programmes of sex ratio and maturity stage analyses. The male and female fish of some species, such as North Sea plaice, Tilapia and Sebastes, have such different rates of growth that they should be treated as separate stocks in stock assessment work. Mortality rates may also differ between sexes. Moreover, where the catch of a species contains a mixture of stocks, maturity data may provide the best guide to the relative proportions of the stocks in the catches and to changes in these proportions.

However, the determinations of sex and sexual maturity stages find their primary application in providing basic knowledge of the reproductive biology of a stock. The information derived from these analyses can be used in ascertaining the age and size at which fish attain sexual maturity, the time and place of spawning and the duration of the cycle from the beginning of the development of the ovary to the final release of eggs. Together with fecundity estimates this information can be used to calculate the size of a stock and its reproductive potential. The data have several practical uses. The age and size at sexual maturity may be important in assessing the optimum age of first capture of a species and the time and place of spawning can be used to plan fishing tactics because many species of fish are easiest to catch when they congregate to spawn. Conversely it may be considered advisable to limit fishing on an overexploited stock in which future recruitment is jeopardized by a low spawning stock.

The two major groups of fish, teleosts and elasmobranchs, differ so much in their reproductive biology that they will be dealt with separately. Most of the literature is concerned with the description of teleost fecundity and almost all of that is limited to description of species which lay all their eggs within a short period.

5.2 Teleosts

5.2.1 Sex determination

Determination of sex does not normally present any serious difficulties. In some species, e.g., salmon, characins and some cichlids, this can be done from external characters without opening the fish to expose the gonads. It is possible to sex plaice, and many other North Sea flatfish by holding them towards a light; the body cavity of the female is longer than that of the male (Fig. 5.1). Normally the body cavity has to be split open. Even after exposure of the gonads, differentiation between the sexes by gross examination may be difficult or impossible in small virgin individuals, as shown by Howard and Landa (1958) for Anchoveta and by Schaefer and Orange (1956) for skipjack and yellowfin tuna. In specimens which are beyond the immature virgin stage the distinction between sexes can normally be made easily by eye examination; ovaries are usually tubular, pink, and granular while the testes are flat, white and their ventral edges frequently have a wave-like outline. In other species, for example herring, the sexes of virgin fish can be distinguished from the colour of the gonads; the ovaries are red and the testes are white-grey/brown. The testes also have a more flattened knife-edged shape than the ovaries.

5.2.2 Maturity stages

The term 'maturity stages' has a peculiar, but generally accepted meaning in fisheries biology. It is taken to mean the degree of ripeness of the ovaries and testes of a fish and not whether the fish has sexually matured or not. Thus the term 'first maturity' is used to

Rastrelliger appears to meet most of the requirements and to be applicable, with minor modifications, to a wide range of partial spawners. This is given in Table 5.2.

5.2.3 Gonad indices

Determination of maturity stages by visual examination using maturity keys lacks precision because it relies upon subjective judgement. It is adequate for many purposes but a more precise and more objective method is desirable in some cases. The most practical way of achieving this with the minimum cost and labour is to calculate a 'gonad index'. This can be expressed as

$$\frac{w}{L^3} = 10^8$$

where w = weight for both gonads (g), and L = total length of the fish in millimetres. Since the weight of most fish is closely proportional to the cube of the length this gives an index which is approximately proportional to the relative weight of the gonads. For female fish it is also a relative measure of the ova diameter, independent of the length of the fish (Schaefer and Orange 1956).

5.2.4 Length - maturity keys

It is not normally possible to do maturity sampling on commercial fish markets; often the fish are landed with the viscera and gonads removed. Also, fish markets do not normally have the facilities required for this type of work. It is therefore customary to do maturity staging on special samples either set aside ungutted for this purpose by the crews of commercial vessels or collected on research vessels. These samples may not be completely representative of the total catch because there is often a close relation between maturity stage and the length of fish. Therefore it is better to construct a maturity-length key and to use this to estimate the maturity stages in the population.

Exactly the same method of doing this is used as for constructing an age-length key (see section 4.4.2) except that the number of fish of each maturity stage replaces the number of fish per age group in each length stratum. The method of raising the maturity-length key to obtain the maturity stages in the total number of fish landed is then calculated in the same way as raising an age-length key to the age composition of the total landings.

5.2.4.1 Bias in the maturity-length key

The distribution of maturity stages in the commercial landings may not be representative of the distribution of maturity stages within the population in the sea. This can occur because fish in different maturity stages are not equally available or vulnerable to the fishery. For example, ripe herring are poorly represented in the catches of the Scottish drift-net fleet from the north-western North Sea. There are two reasons for this; ripe fish do not arise at night to the depth fished by a drift net to the same extent as fish in lower maturity stages, and the spawning grounds in this area are difficult to fish by drift net. Similarly, Schaefer and Orange (1956) have reported that yellow-fin tuna become unavailable to the American fishery in the Pacific on the approach of spawning, presumably because they then move either offshore or into deeper water to spawn. Such phenomena should be apparent in the results after sampling throughout a complete sexual cycle. They can probably be rectified only by appropriate research vessel sampling.

5.2.5 Fecundity

Knowledge of the fecundity of a species is an important factor in fish stock management. It is used to calculate the reproductive potential of a stock and the survival from egg to

describe a fish which is spawning for the first time. For all other animals the term 'maturity' is used because an animal reaches maturity (the ability to reproduce) once. 'First maturity' implies more than one 'maturity'. The inconsistency of the expression and the use of the term 'maturity stage' probably arose because the first fish for which 'maturity stages' were described had one, clearly marked, annual breeding cycle with a long interval in which the gonads returned almost to their virgin stage. However, it would be more logical to talk of 'maturity' and 'spawning' stages.

Routine assessment of maturity stages is normally done by assigning individuals to stages by characters which can be differentiated with the naked eye. A more refined distinction between stages can be made by histological examination but this is not a practical approach in routine sampling because it takes too long. The aim should be to examine a large number of fish at frequent intervals to get a representative picture of the stage of maturity of the population and the changes in this with time.

A large number of keys for maturity staging have been devised and described in the literature. These cover the minor differences between species and those within a single species, giving various degrees of refinement. Because gross naked eye staging inevitably means subjective judgement, too high a level of refinement is unjustified. A scale of not more than 8 stages is probably suitable for most species.

5.2.2.1 Total (isochronal) spawners

'Total spawners' are those species in which, after maturation of the gonads begins, all the eggs or sperm which are going to be spawned by the individual fish in a single breeding period develop synchronously. Their release takes place over a short period of a week or so and the breeding season is clearly defined. This is the commonest type, at least in species of northern latitudes.

Maturity staging of total spawners is usually simple because nearly all the developing eggs in the ovary are at the same stage and can fairly easily be allocated to that stage on visual criteria of size, colour, and texture, although these stages may have no very clear histological significance. A typical and fairly satisfactory key for classifying maturity stages in total spawners which is widely applicable in species of this type is that of Maier (1908) given in Table 5.1. This can be modified to suit the species under study. For example it is often difficult to separate males into 8 stages.

This scale adequately meets the basic requirements. It (a) distinguishes in low maturity stages between virgin fish and fish which have spawned previously, thus providing the possibility of fixing the mean age and range of ages at maturity; (b) clearly defines the stage both when release of eggs and milt is in progress and when it is completed, allowing accurate fixing of the beginning, peak, and end of the spawning period; (c) divides the intervening period into a reasonable number of stages, from which an approximate prediction of spawning time can be made and (d) is capable of rapid determination with the minimum of equipment, thus permitting large samples to be analyzed under field conditions.

5.2.2.2 Partial (heterochronal) spawners

'Partial spawners' are those in which spawning by individuals takes place over a protracted period and in which ripening eggs at very different stages of development can be found at any one time in the same ovary both before and during spawning. This situation is found, for example, in North Sea mackerel, in sprats and in a number of species, such as Rastrelliger and Chilean hake, in tropical and sub-tropical waters.

The construction of a maturity scale for partial spawners is more difficult because there is a range of development stages in an individual gonad at any one time and the differentiation achieved will inevitably be less precise. A key originally devised for

recruitment, on both of which a judgement of the minimum adult stock necessary to maintain recruitment can be made. A knowledge of fecundity and the sex ratio of the adult stock are also needed to calculate the size of the stock from estimates of annual egg production which will be described in section 7. A third use of fecundity data is to discriminate between stocks in fisheries exploiting a mixture of two or more stocks with different fecundities (Baxter, 1963).

The problems of estimating fecundity depend upon several factors: the absolute number of eggs produced; whether the species is a total or partial spawner; on the degree of differentiation there is between the size of eggs which will be spawned in that season and any immature eggs present which will be carried over to the next spawning season.

5.2.5.1 Total spawners

As in maturity stage estimations the simplest case is that of total spawners. Fecundity can be estimated by removing the ovaries from females in Stages III to V of the scale given in Table 5.1. The fish from which they are taken should be measured and the necessary parts taken for age determination. The ovaries should then be preserved in modified Gilson's fluid (100 ml 60% alcohol, 800 ml water, 15 ml 80% nitric acid, 18 ml glacial acetic acid, 20 g mercuric chloride) with a label to identify them with the fish from which they were removed. The ovaries should be shaken periodically whilst in the Gilson's fluid to help loosen the ovarian tissue and to ensure rapid penetration of the preservative. After at least 48 hours in preservative the eggs can be completely liberated from the tissues by vigorous shaking.

The most accurate way of estimating the number of eggs in the ovaries is to count them all. This can be done with egg-counting machines but because the fecundity of most fish is so high this is impractical to do manually. Instead, it is necessary to estimate the number of eggs by sub-sampling. There are two basic methods of doing this, gravimetric and volumetric.

Gravimetric sampling as its name implies is based on weighing the eggs. After the eggs have been liberated from the ovarian tissues, they are thoroughly washed and spread on blotting paper to dry in air. The total number of eggs is then weighed and random samples of about 500 eggs are counted out and weighed. The total number of eggs in the ovaries is then obtained from the equation $F = \frac{nG}{g}$ where F = fecundity, n = number of eggs in the subsample, G = total weight of the ovaries, g = weight of the subsample in the same units.

If Gilson's fluid is not available it is possible to estimate fecundity using this method by weighing both ovaries and then taking subsamples which are weighed. The eggs are teased out with a pair of needles and counted. At least three subsamples should be taken from each ovary, one from the anterior, one from the middle and one from the posterior. The method is tedious and less accurate than if it had been possible to use Gilson's fluid. Its great advantage is that it does not require large volumes of an expensive fluid and can be used in the field. It is particularly useful for fish with low fecundity and large eggs.

The volumetric method is very similar. After separation in Gilson's fluid the cleaned eggs are put in a measuring cylinder and made up to a known volume with water. Subsamples are then taken by shaking the container until all the eggs are evenly distributed through the water, a subsample of known volume withdrawn with a Stempel pipette, and the number of eggs in the subsample counted. The fecundity is then $F = \frac{nV}{v}$ where n = number of eggs in the subsample, V = volume to which the total number of eggs is made up and v = volume of the subsample.

In practice, it is normally necessary to count more than one subsample from each fish to get a reliable estimate of the fecundity. Replicate counts of subsamples from the same ovary show that the distributions of the individual counts are of the Poisson type. Because the variance in a Poisson distribution is equal to the mean, the number of subsamples required to

give any desired degree of accuracy can be determined from the number counted in the first subsample from the equation, % accuracy = $\frac{100}{m\sqrt{n}}$ where the mean, m, is taken as the count in the first subsample and n is the required number of subsamples.

This method is subject to considerable bias because it is very difficult to get all the eggs evenly distributed throughout the measuring cylinder. Unless great care is taken the density of the eggs is higher at the bottom of the cylinder than the top and in the middle of the cylinder than at the sides. The degree of bias is likely to be greatest if one person has to shake the cylinder and take the subsamples.

Total counts of egg numbers in an ovary can also be made using automatic counters either of the type described by Parrish, Baxter and Mowat (1960) (Fig. 5.2a) or the Decca Master-count type described by Boyar and Clifford (1967) (Fig. 5.2b). The advantage of using these machines is that sampling error, inherent in any subsampling technique is avoided but their disadvantage is their slowness.

Automatic fish egg counters, based on the Coulter counter, are now being designed which enable the numbers of particles of several pre-set sizes to be counted. This will eliminate one of the drawbacks of present counters, which count all particles, large and small. In the new counters the number of particles corresponding to the size of the eggs only is taken as the fecundity.

5.2.5.2 Partial spawners

To date, fecundity analysis has been largely confined to total spawners because it is so difficult to estimate the fecundity of partial spawners. In their early maturity stages, all the oocytes due to be spawned in one spawning cycle may not yet have been differentiated and, in later stages, some of the first eggs to develop may already have been spawned. To get an adequate estimate of annual fecundity in such species, it is necessary to obtain information on the number of spawnings per year, the number of eggs shed at each spawning and the relation between these factors and the size and age of the fish. Fischer and Balboutin (1970) have described useful techniques for sorting oocytes into size groups and subsampling them in such species while Macer (in press) has described a method for the horse-mackerel (Trachurus trachurus) based on histological examination of the ovaries over a complete spawning cycle. His method is very time-consuming and is not applicable to routine sampling programmes but it does allow a solution of the problem.

5.3 Elasmobranchs

5.3.1 Sex determination

The sex of elasnobranchs can always be determined from external characters because male fish have a pair of mixopterygia (intromittent organs, claspers) which are visible from an early stage of development on the inside edge of the pelvic fins (Fig. 5.3). The females do not have mixopterygia.

5.3.2 Maturity stages

The maturity of males can be easily and best defined from the state of development of the mixopterygia. These of immature fish are small and flaccid and do not reach the posterior edge of the pelvic fin (Fig. 5.3a). In maturing fish the mixopterygia are larger; they extend to the posterior edge of the pelvic fins and the internal instructure is visible but soft and not ossified (Fig. 53b); in mature fish the mixopterygia extend well beyond the posterior edge of the pelvic fin, the internal structure is visible and is hard and ossified (Fig. 5c).

Maturity of females must be determined by internal examination. The reproductive system of females consists of ovaries (usually two but in some species one only is present), shell

glands and oviducts (Fig. 5.4). In immature fish the ovary is barely discernible and it contains no eggs; the shell gland is also very small and the oviducts are thick-walled and white (Fig. 5.4a). In maturing fish white eggs are visible in the ovary but the remainder of the reproductive system is similar to that of immature fish (Fig. 5.4b). In mature fish the ovaries contain yellow eggs, except immediately after ovulation in viviparous species and at the end of the spawning season in oviparous species; the shell gland is enlarged and the ovidcuts distended and, in viviparous species, thin-walled, flaccid and often highly vascularized (Fig. 5.4d). In viviparous species maturity is also associated with changes in the size of the cloaca (Fig. 5.4c).

5.3.3 Fecundity

Elasmobranchs are either oviparous (egg laying) or ovoviviparous (the eggs are retained within the mother until the young are capable of free existence but no food is supplied by the mother to the young) or viviparous which is similar to ovoviparity except that there is some type of connection between the mother and the young by which they are fed.

Determination of the fecundity of the two live bearing groups depends upon knowing both the number of young and the length of the pregnancy cycle. The former can be determined by counting the developing, yellow eggs in the ovary or the number of young in the 'uterus' (the combined oviducal-cloacal system). In the latter instance care must be taken to ensure that the young have not been prematurely aborted during capture and in both cases it must be established that cannibalism does not take place in the uterus. (In some species the first young to hatch eats the remaining eggs). The duration of the pregnancy cycle is less easy to determine. The best way is to obtain samples over one year and to determine the average length of the young and the volume of their yolk sacs. Any inconsistent sudden increases in the growth of the young should be treated with suspicion. Pregnancy cycles of live-bearing elasmobranchs are often very long, two years for the spiny dogfish Squalus acanthias (Ford, 1922). Often the females in one stage of the cycle are not easy to catch and this can lead to false conclusions about the duration of the cycle (see Holden (1974) for a full discussion of these problems).

Oviparous species are partial spawners and pose the same problems as teleost partial spawners. The only study to date of this problem is that on the thornback ray (Raja clavata) by Holden (in press). He determined the occurrence of egg capsules in samples taken throughout the year and then equated the month in which the occurrence of egg capsules was at a maximum with the maximum rate of egg laying observed in aquaria (1 egg every 24 h). For other months the rate of egg laying was assumed to be proportional to the percentage occurrence of egg capsules. This, multiplied by the number of days in the month, gave the number of eggs paid in that month. For example, let the percentage occurrence in April (30 days) be 40% compared with 80% in June, the highest percentage occurrence of egg capsules observed. 80% is taken as equivalent to one egg laid in 24 h and therefore 40% is equivalent to 1 egg laid every 48 h which in 30 days would result in 15 eggs being laid.

5.4 Fecundity - Length Relationships

In all species fecundity appears to be related to the length of the fish by an equation of the type $F = aL^b$ (Fig. 5.5). Such an equation can be converted to a linear form by converting to logarithms, i.e. $\log F = a + b \log L$ where F = fecundity, L = length of the fish and a and b are constants. The value of b is normally close to 3 although for some elasmobranchs it is nearer 2. Pitcher and MacDonald (1973) have shown that if mean length is used in such an equation for the estimation of a stock the number of eggs is underestimated because small fish have proportionately fewer eggs than large fish.

The constants are not the same for all species and for one species both a and b may alter with time. Also stocks of the same species can be separated from statistically significant differences between values either of a or b in the fecundity-weight and fecundity-length relationships. As the weight of a fish is normally closely proportional to the cube

of the length the fecundity-weight relationship is linear for those species for which b approximates to 3. (Fig. 5.5), and is of the form $F = aW + b$, where W is the weight of the fish. Another way of expressing such differences is by using a 'fecundity index' expressed as either fecundity/weight or fecundity/length^3. The latter is the better expression because it avoids the variance in weight within a stock during a season caused by growth of the gonads.

5.5 References

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Table 5.1. An eight-point maturity scale for total spawners.

Stage	State	Description
I	Virgin	Sexual organs very small, situated close to vertebral column. Testis and ovary transparent, colourless or grey. Eggs not visible to naked eye.
II	Maturing virgin	Testis and ovary translucent, grey-red. Length of gonads $\frac{1}{2}$, or slightly more, of length of ventral cavity. Individual eggs can be seen with magnifying glass.
III	Developing	Testis and ovary opaque, reddish with blood capillaries. Occupy about $\frac{1}{2}$ of ventral cavity. Eggs visible to naked eye as whitish granular material.
IV	Developed	Testis reddish-white, no milt produced under pressure. Ovary orange-red. Eggs clearly discernible, opaque. Testis and ovary occupy about $^2/_3$rds of ventral cavity.
V	Gravid	Sexual organs fill ventral cavity. Testis white. Drops of milt produced under pressure. Eggs completely round, some already translucent and ripe.
VI	Spawning	Roe and milt run under slight pressure. Most eggs translucent with few opaque eggs left in ovary.
VII	Spent	Not completely empty, no opaque eggs left in ovary.
VIII	Resting	Testis and ovary red and empty. A few eggs in state of resorption.

Table 5.2. A five-point maturity scale for partial spawners.

Stage	State	Description
I	Immature	Ovary and testis about 1/3rd length of body cavity. Ovaries pinkish, translucent; testis whitish. Ova not visible to naked eye.
II	Maturing virgin and recovering spent	Ovary and testis about ½ length of body cavity. Ovary pinkish, translucent; testis whitish, more or less symmetrical. Ova not visible to naked eye.
III	Ripening	Ovary and testis is about 2/3rds length of body cavity. Ovary pinkish-yellow colour with granular appearance, testis whitish to creamy. No transparent or translucent ova visible.
IV	Ripe	Ovary and testis from 2/3rds to full length of body cavity. Ovary orange-pink in colour with conspicuous superficial blood vessels. Large transparent, ripe ova visible. Testis whitish-creamy, soft.
V	Spent	Ovary and testis shrunken to about ½ length of body cavity. Walls loose. Ovary may contain remnants of disintegrating opaque and ripe ova, darkened or translucent. Testis bloodshot and flabby.

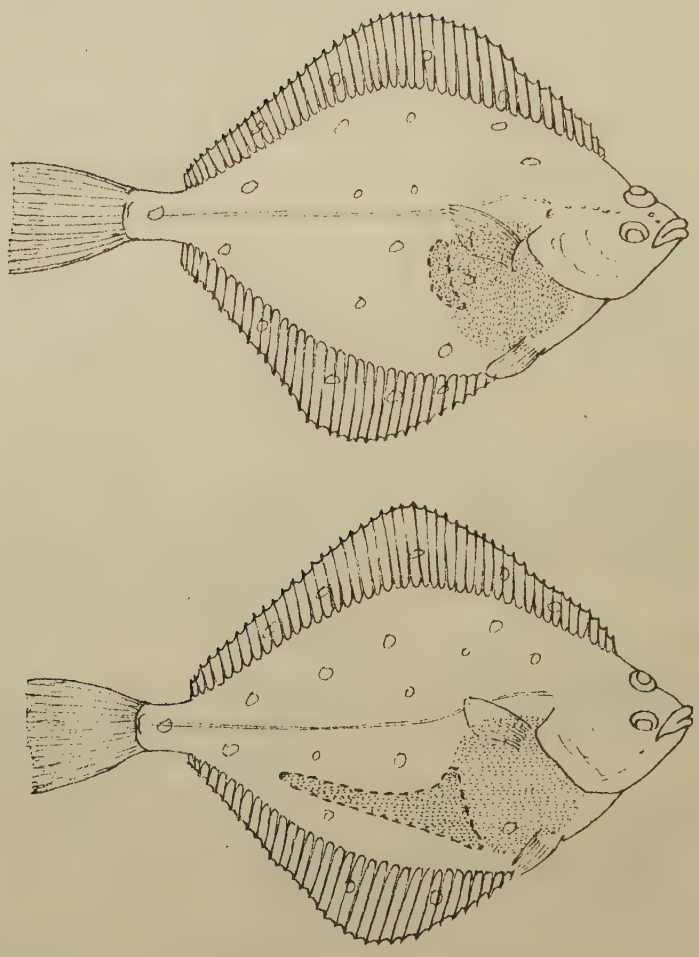

Fig. 5.1 Sex differentiation in plaice - above: male; below: female

Fig. 5.2a Automatic fish egg counter

Fig. 5.2b Automatic fish egg counter

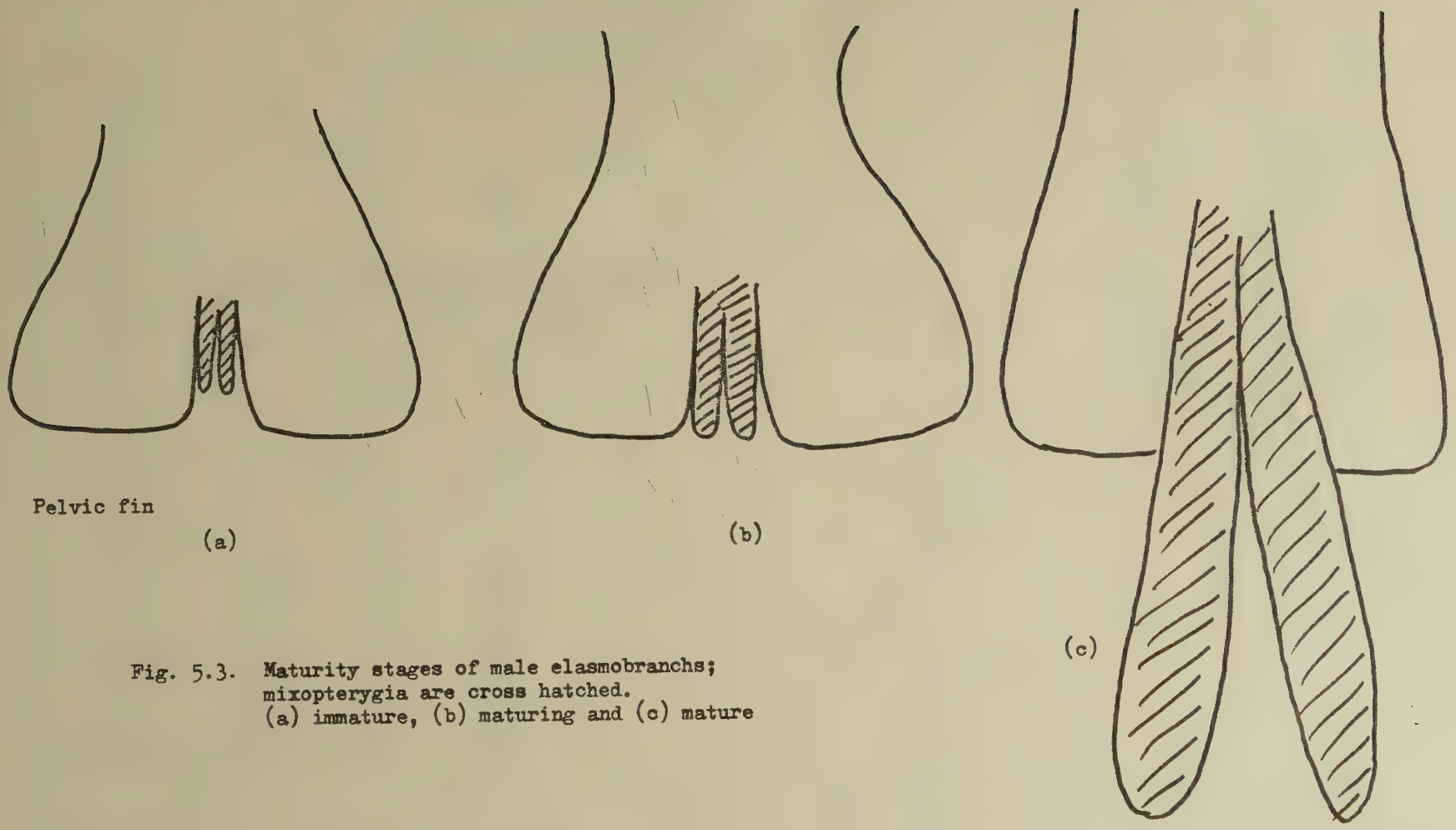

Fig. 5.3. Maturity stages of male elasmobranchs; mixopterygia are cross hatched. (a) immature, (b) maturing and (c) mature

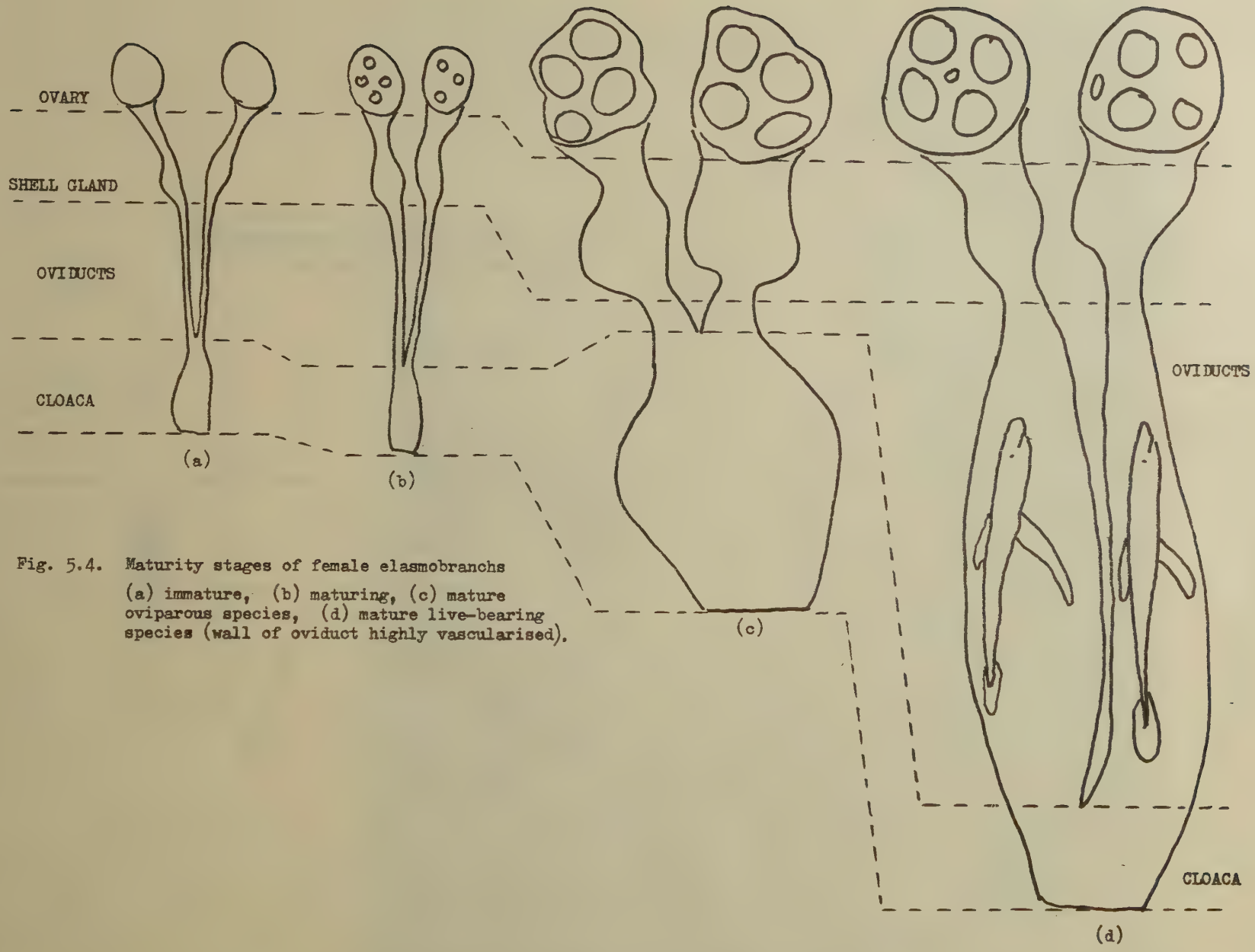

Fig. 5.4. Maturity stages of female elasmobranchs (a) immature, (b) maturing, (c) mature oviparous species, (d) mature live-bearing species (wall of oviduct highly vascularised).

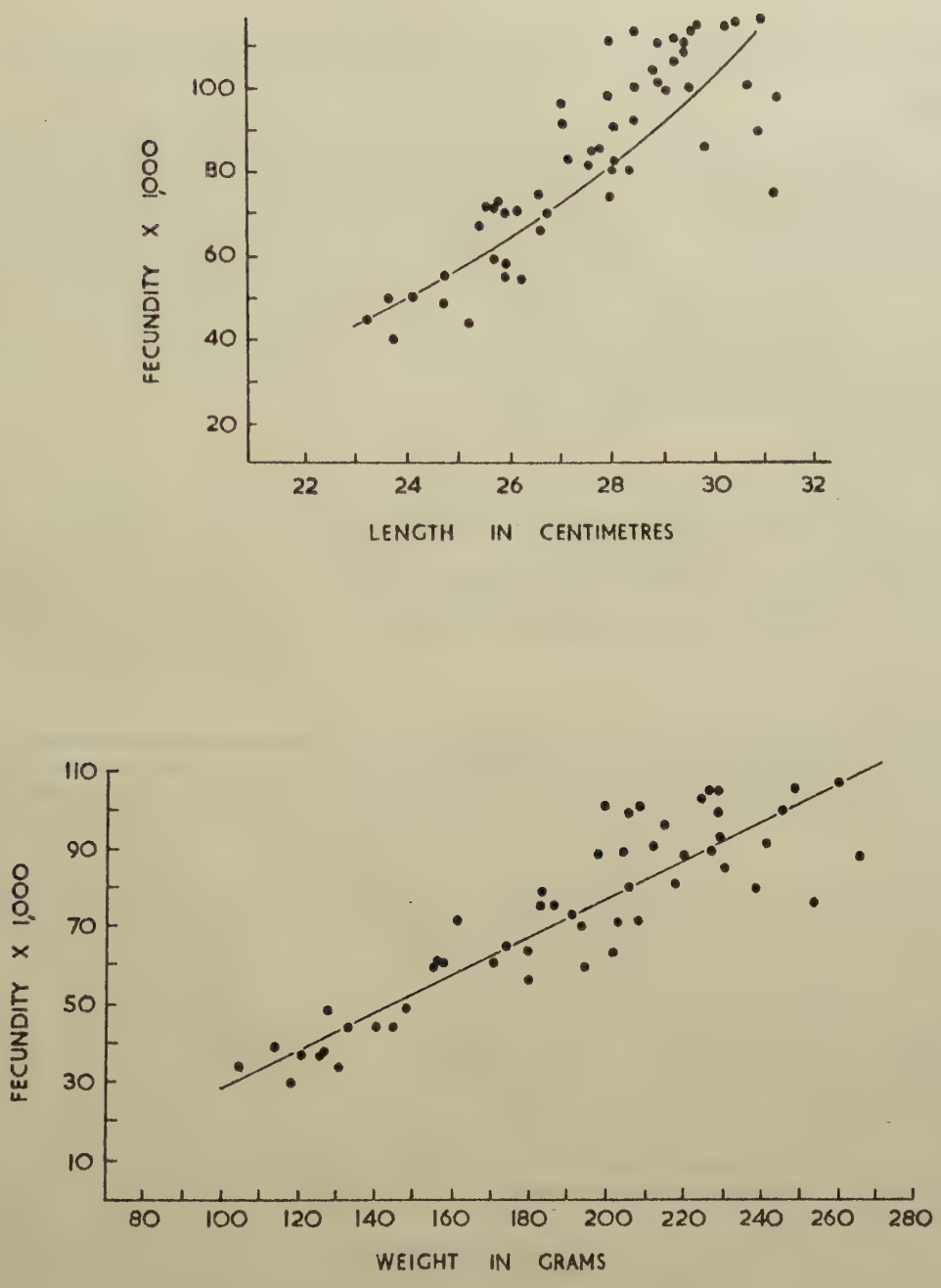

Fig. 5.5 Fecundity/length and fecundity/weight relationships in herring

6. FOOD AND FEEDING

6.1 Introduction

Investigation of stomach content has traditionally been an important field of activity in fisheries biology, but it is one in which there are great difficulties in correlating the results with the research made in the other fields. Investigations of the food of the fish cannot be considered in isolation but have to be discussed in relation to the whole marine environment, of which the fish constitute single elements. Therefore, a brief survey of the most important processes in aquatic ecology must be made, with particular reference to feeding.

6.2 Some Principal Lines of General Ecology

6.2.1 What is ecology?

Living organisms interact with each other and with their non-living (abiotic) environment in many ways; no organism exists independently of its environment. It is the study of these interrelationships which is called ecology. It is possible to study the ecology of one species in relation to its environment or a whole group of species and their interactions with both each other and their physical surroundings. Thus, ecology is concerned not only with the biological disciplines but also the physical and chemical sciences.

6.2.2 The ecosystem

Any area of nature in which materials are being exchanged between living organisms and their abiotic environment forms an ecological system or ecosystem. This concept is useful as it stresses the interdependence of the components involved. Although it is hardly possible to demarcate any area in nature that is not influenced by neighbouring areas, one may, nevertheless, consider a pond, a lake or even part of a forest as an ecosystem.

To understand the dynamics of such a self-sufficient ecosystem as a functional unit, its component parts must be looked at in some detail first.

6.2.3 Steps and components of the ecosystem

The following steps in the operation of the ecosystem (Figs. 6.1 and 6.2) can be recognized from a functional point of view:

1. Reception of light energy.

2. Production of organic material by autotrophic (self-nourishing) producers utilizing inorganic nutrients.

3. Consumption of the organic material by heterotrophic (other methods of nourishment) consumers.

4. Decomposition of the organic material to inorganic nutrients, suitable for the producers, by saprophytic micro-consumers, chiefly bacteria and fungi.

The main producers are the chlorophyll-possessing green plants; synthesizing bacteria usually play only a very minor role.

The consumers comprise all the other living components present. They include the herbivores (plant-eaters), which feed directly on the producers, and the carnivores (predators), which feed on the herbivores or other carnivores. They also include parasites, scavengers, (carrion-eaters) and saprophytes. Although it is convenient to list the

decomposers, consisting of bacteria and fungi, as a separate entity because of their specific role and their indispensability they are of course also consumers.

The inorganic nutrients comprise a large number of elements present in the form of dissolved salts. The most important are nitrogen and phosphorus followed by potassium, calcium, sulphur and magnesium. Some elements are needed in extremely minute amounts and are therefore referred to as micro-nutrients.

6.2.4 Food chains and trophic levels

The production of organic substances (food) by photosynthesis is a process involving transformation of light energy into potential chemical energy. The transfer of this food energy from the producers through a series of consumers is called a food chain, each organism through which it is passed being a link in the chain.

For sake of simplicity three different food chains may be recognized:

1. The carnivore chain, where the energy is passed from smaller to larger organisms.

2. The parasite chain, where the energy is passed from larger to smaller organisms.

3. The saprophyte chain, where the energy is passed from dead organic matter to micro-organism in most cases.

In reality food may be passed through parts of all three chains before it is finally decomposed into inorganic nutrients by the bacteria and fungi found at the end of every food chain. In other words, the species population within a community or ecosystem form many food chains which interconnect, anastomose or cross each other in a complex pattern, which is usually referred to as the food web.

Organisms which belong to the same link of the food chain as counted from the producer level are said to belong to the same trophic level. Thus the plants constitute the first trophic level, the herbivores the second, and the carnivores feeding on herbivores the third trophic level. Secondary carnivores feeding on third level carnivores belong to the fourth trophic level and so forth. However, there is a very definite limit to the number of possible links in a food chain, and consequently also to the number of trophic levels in any ecosystem. The reason for this is that only about 10 percent of the available energy is assimilated in passing from one trophic level to the next. At the top of the food chain there are usually only one or two major predators. The number of species in each trophic layer increases with approach to the first layer, giving rise to what is called a pyramid of numbers. For the major predators introduction of small amounts of pollutants into the first trophic layer can have fatal consequences because it is eventually concentrated in them.

6.2.5 Gross production and net production

The laws of thermodynamics state that energy cannot be created or destroyed, but also that it cannot be transformed from one type to another without partial dispersion into heat energy. This means that the transformation of light energy into potential chemical energy in the form of organic compounds in the plants cannot be 100 percent efficient. Only a very small portion of the light energy absorbed by green plants that is transformed into food energy (gross production) because most of it is dispersed as heat. Furthermore, some of the synthesized gross production is used by the plants in their own respiratory processes, leaving a still smaller amount of potential energy (the net production) available for transfer to the next trophic level.

The loss of energy is generally referred to as the respiratory loss because the organisms utilize the food energy by oxidizing it. Because of the respiratory losses the food chains cannot be very long and the number of trophic levels in natural communities is therefore

seldom more than four or five and often only three. It also means that the total amount of food available decreases with increasing trophic level. For this reason, the largest animals are found feeding on either plants or other animals which are in a low trophic level as, for example, whales on krill and elephants on plants.

Among animals the gross production corresponds to the food assimilated, which means food ingested and absorbed by the intestine. The net production is here equal to food assimilated minus respiration.

While most of the energy lost within an ecoystem is due to the respiratory processes, there are other losses which affect the individual organisms. Some of the potential food is not ingested, but is either decomposed directly or is stored or is exported out of the system or community. Another source of loss is that not all of the food ingested is actually assimilated; some passes through the alimentary canal and is lost as faeces.

As stated earlier, as the organisms die they are attacked by the decomposers, which derive their energy from them by reducing their organic contents to inorganic nutrients. As also indicated earlier, these nutrients can then be used by the producers anew with the result that the materials involved are continuously circulating in the system. However, the energy flow is strictly passed along a "one-way street". To keep an ecosystem going light energy must be continually supplied.

6.2.6 Production and ecological efficiencies

As we have seen, true production of organic matter takes place only in the chlorophyll-possessing plants and certain synthetic bacteria, and this has been referred to as the primary production. However, copepods and euphausids, for example, are often referred to as meat producers or "key industry" animals because they convert plant material into protein that can be assimilated by the animals which eat them but which themselves could not exist on plant material. In reality, of course, they only assimilate and store energy derived from the primary producers. To avoid confusion it would be better to call them secondary producers, a term which of course fits animals at higher trophic levels just as well because they too - although indirectly - utilize the primary production of the plants.

From a practical point of view it is often desirable to find out how big is the secondary production of certain animals in a given area, say a fishing bank, or even more important, whether a known production can be increased. Production estimates must be based on such factors as standing crop (biomass), rate of removal of materials and rate of growth, including growth of young born or hatched during the census period. The turnover rate is also of interest when short-lived species are involved as is practically always the case within ecosystems in the sea. The biological production must be expressed per time unit. A large standing crop is by no means synonymous with a large production rate. To take an easily visualized example, a pasture grazed by cows may have a very small standing crop of grass because the production is being eaten as it is being produced, but it may nevertheless have a higher production rate than a neighbouring ungrazed pasture with a very large standing crop.

Quantitative relations between the various trophic levels can be calculated provided the production rates are known for each level concerned. Relationships of this nature within trophic levels are also of considerable interest. Expressed as percentage ratios the results of such calculations are often referred to as ecological efficiencies because they are concerned with the efficiency of energy transfer at different points along the food chain. Thus they are important to our understanding of the dynamics in ecosystems. Moreover, most of the efficiency ratios are meaningful with regard to single species populations as well as to whole trophic levels.

Unfortunately much confusion exists in the terminology used by various authors, and it is not always clear to which efficiency ratio an author has really wished to refer. Odum (1959) has made an attempt to define the various ratios, based on his energy flow diagram, and this is certainly a good method of illustrating the complexities involved (Fig. 6.3).

Among fishery biologists the most common way of describing the efficiency is by the conversion factor, i.e. the ratio of the weight of the food consumed by the fish and the growth in weight. Some authors express this conversion factor as the nutritional coefficient. From Fig. 6.3 it is seen that the conversion factor is the reciprocal value of what Odum calls the ecological growth efficiency. The value of the conversion factor is traditionally defined as 10, but in fact it can be both much higher and much lower, e.g. in trout farms in northern Europe the conversion factor is about 5.

However, it is important to stress that none of the ecological efficiencies are constant for any species population or for a whole trophic level. They are dependent on a number of abiotic factors such as temperature and salinity, as well as biotic factors such as type, abundance and distribution of available food, and the age of the consumers; for example, larvae and young ones of all species investigated have much lower conversion factors than older animals.

6.3 Estimation of the Food Intake of Fish

Almost all the work that has been done upon the food intake of fishes has been qualitative, rather than quantitative. That is, workers have described the occurrence of food found in the digestive tract, usually in the stomach only. This tells what the fish has eaten and approximately in what proportions but it does not describe how much of each food species is eaten. The reaon for the lack of quantitative work is that it is very time-consuming.

6.3.1 Qualitative assessments of food intake from stomach content analyses

As soon as possible after the fish has been caught all the digestive tract is dissected out, and if the investigation cannot be finished at once, possibly because of lack of laboratory facilities, the material must be preserved in 4 percent buffered formalin.

Later in the laboratory the different sections of the digestive tract are opened and the individual groups of organisms are sorted out foridentification. This is most easily done with a binocular-dissecting microscope. To illustrate the methods in use and to describe their advantages and disadvantages a series of results will be considered based on the examination of the stomach contents of two Lates niloticus (Table 1).

6.3.1.1 Frequency of occurrence

The occurrence of each food item is recorded and expressed as the percentage occurrence of all food organisms. The method is very quick and easy but it underestimates the importance of the larger species. In the example, 40 percent of all the food occurrences were Odonata nymphs. The stomach contents of these two L. niloticus could have consisted almost entirely of nymphs, each with a very small Tilapia galilaea but the results give no indication whether this might be a true interpretation of the data.

6.3.1.2 Numerical occurrence

The numbers of each food item are recorded and the results expressed as a percentage of the total number of food items present. This method overestimates the importance of small food organisms, in this case the Odonata nymphs. It is not satisfactory with plant food, except with microscopic examination of algae. In the example given the plant material could be a small piece of grass or a large piece.

6.3.1.3 Dominance

The method is similar to the frequency of occurrence method except that the results are expressed in terms of the number of fish in which the food item occurred expressed as a percentage of the total number of fish. The method gives an indication of what are the main food species but does not indicate their relative importance as sources of energy.

6.3.1.4 Total volumes

The entire volume of the stomach contents is measured. The contents are then sorted into different types of food and the volume of each determined. Results are usually reported as percentage of the total volume.

This method is more time-consuming than any of the previous methods but it describes accurately the relative importance of each food species and the total volume (ξ) indicate the quantity of each item being eaten.

6.3.1.5 Percentage volume

This method is identical to the previous method except that the volume of each food item is first expressed as a percentage volume of the total stomach contents from which it was removed and then an average taken for all the fish sampled. The advantage of this method over the previous one is that the final results will be more representative of the feeding habits of a group of fish if one or two individuals in that group have been feeding very heavily on one particular food item. The disadvantage is that the information on the actual volume of the stomach contents is lost.

6.3.1.6 Gravimetric

Total weights of all food items are determined. This method is very similar to the volumetric method, over which it has little advantage unless the sample is dried so that only the dry weight is determined. Results are usually presented as percentages of the total. If wet-weights are determined the food items must be placed on a blotter for a moment to remove excess moisture. This problem of removing excess moisture makes the method somewhat subjective and therefore dry-weight is better, although much more time-consuming.

6.3.1.7 Points method

Points are given to each item. The number of points depends upon both whether the organism is very common in the stomach contents (highest number of points) or rare (lowest number) and upon its size (more points for large than small size). The method may also be modified to take stomach fullness into account. It is rapid, easy and requires no special apparatus; with experience the method can be very accurate. In the example shown (Table 6.1) the points allocated give a result similar to both the volumetric and gravimetric methods.

Further detail about these methods is given by Rounsefell and Everhart (1953).

6.3.1.8 Discussion

All these methods describe, with a greater or lesser degree of precision, the amount of food which the two L. niloticus, which were used as an example, had in their stomachs; the best being the volumetric and gravimetric methods. The sum of the actual volumes and of the weights also indicates the degree of fullness of the stomach, which enables feeding cycles to be described. The points system is also good if used objectively and has the added advantages of ease and quickness. It can also be adapted to take into account fullness of the stomach.

However, none of these methods describes the quantity of each food item being eaten. In the example used, T. galilaea may take a long time to digest and be identifiable long after Odonata nymphs cease to be. During the time it takes to digest one T. galilaea 20-30 Odonata nymphs might have been eaten and digested but at any one time only 4-6 might be recognizable in the stomach. On the other hand, some food items might have been regurgitated upon capture. While the qualitative methods allow the construction of food chains they do not describe the energy flow through those food chains nor allow the importance of say, predation by one commercially-valuable species on another equally valuable species, to be determined. If answers to these problems were known it might in some instances be considered advisable to reduce the abundance of a predator species to allow an increase in abundance of its prey, especially if the prey were at a lower trophic (more efficient) level. These questions can be answered by qualitative studies only.

6.3.2 Quantitative assessments of food intake

Quantitative feeding studies take considerable time and are therefore the work of the specialist. Only a brief outline of the methods used will be given. Firstly the unit in which energy flow is to be measured is chosen, calories and nitrogen being the two commonest. Secondly, feeding experiments are conducted in aquaria with the different food materials which the species under study eats in order to determine how efficient it is in converting the food item into fish flesh. For calories, this means determining the calorific value of the selected food, feeding the fish a known weight of this food, collecting its faeces and determining the calorific value of these. In order to translate field observations on the weights and calorific values of food found in stomachs digestion rates must be established by feeding fish and then killing them at known intervals. This may need to be done for more than one temperature. From this information is built up a picture of the daily food intake of fish of various sizes of the same species, how much of the energy from this food it utilizes to maintain itself and to grow. One such study by Daan (in press) shows that large cod in the southern North Sea probably have a big influence on the size of year-classes by eating small 0-group cod and that they also eat large quantities of herring, and soles. Boddeke (1971) has also shown that recent large year-classes of cod have reduced the abundance of brown shrimp (Crangon crangon) off the Dutch coast. Daan has suggested that the total production of commercial species from the southern North Sea might be increased by reducing the abundance of cod by heavy fishing upon the stock. Solution of such predator-prey relationships might alter the manner in which some fish assessments were made.

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Table 6.1 Example of results obtained using different methods of estimation of stomach contents for two Lates niloticus

Stomach contents

L. niloticus 1. 1 Tilapia galilaea 20 cm long, weight 80 g, volume 100 ml
6 Odonata (dragon fly) nymphs each 1 cm long, 0.5 g, 1 ml
Plant material, plus weight 5 g, volume 7 ml

L. niloticus 2. 1 T. galilaea 10 cm, 10 g, 15 ml
4 Odonata nymphs each 1 cm, 0.5 g, 1 ml

Results

Food	Method	Fish	Ln 1	Ln 2		%	Total of which % expressed
	Occurrence						
T. galilaea			1	1	2	40	all food occurrences
Odonata			1	1	2	40	
Plant			1	0	1	20	
	Numerical						
T. galilaea			1	1	2	15.4	all food organisms
Odonata			6	4	10	76.9	
Plant			1	0	1	7.7	
	Dominance						
T. galilaea			1	1	2	100	all fish
Odonata			1	1	2	100	
Plant			1	0	1	50	
	Total volume						
T. galilaea			100	15	115	87.1	total food volume
Odonata			6	4	10	7.6	
Plant			7	0	7	5.3	
	% volume						
T. galilaea			88.5	79	167.5	83.8	food volume
Odonata			5.3	21	26.3	13.1	
Plant			6.2	0	6.2	3.1	
	Gravimetric						
T. galilaea			80	10	90	90	total weight of food
Odonata			3	2	5	5	
Plant			5	0	5	5	
	Points						
T. galilaea			50	10	60	85.7	food
Odonata			5	4	9	12.9	
Plant			1	0	1	1.4	

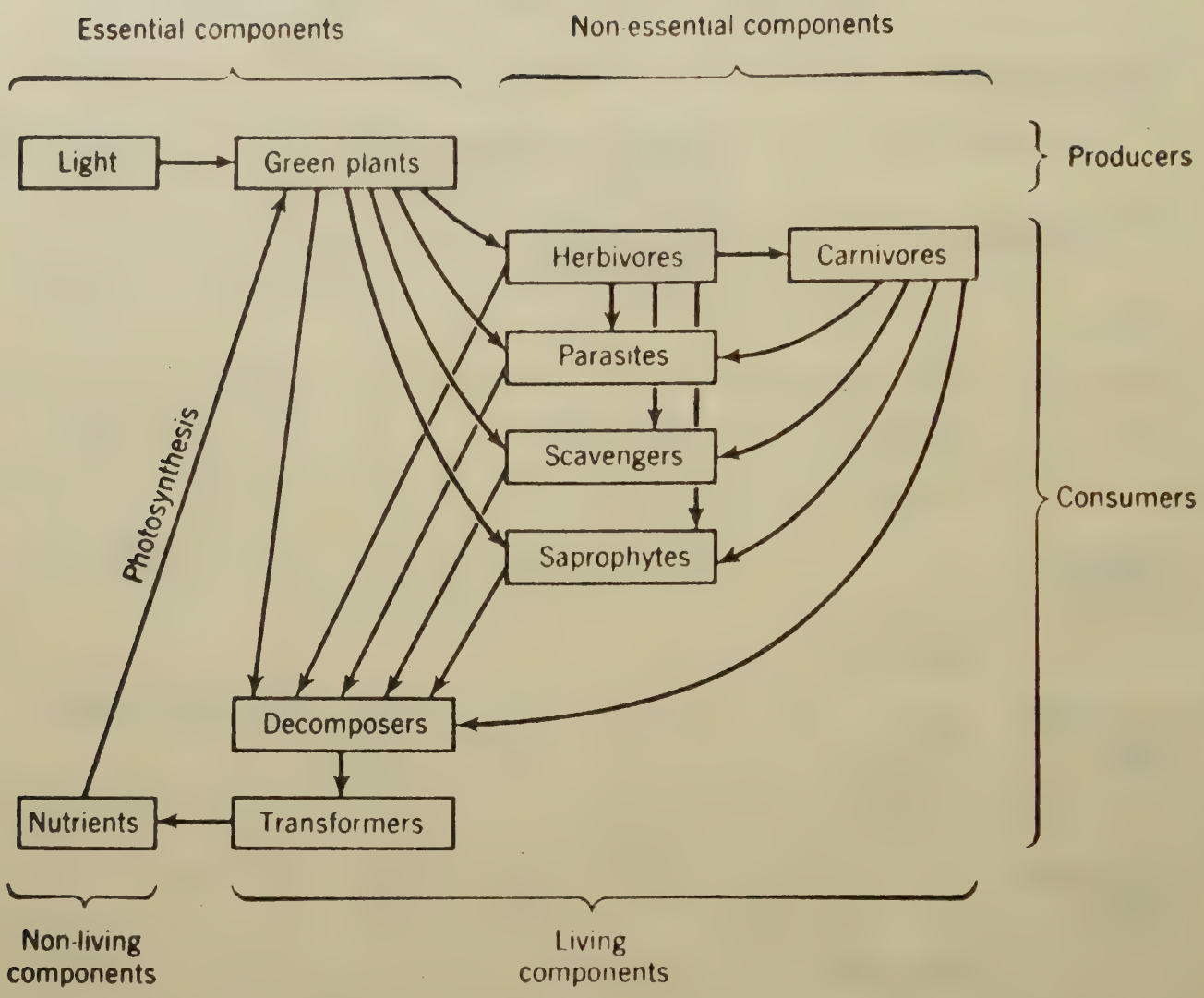


Fig. 6.1 Principal steps and components in a self-sufficient ecosystem (from Clarke, 1954)

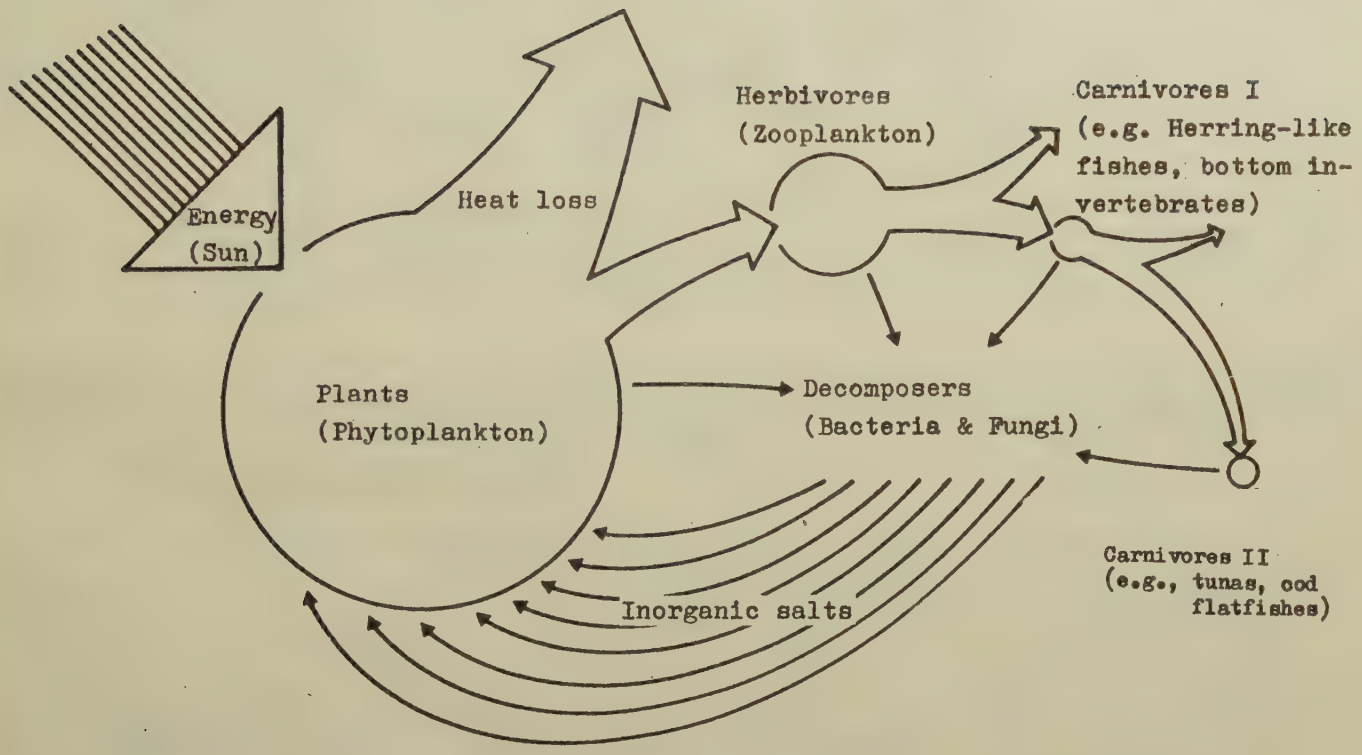
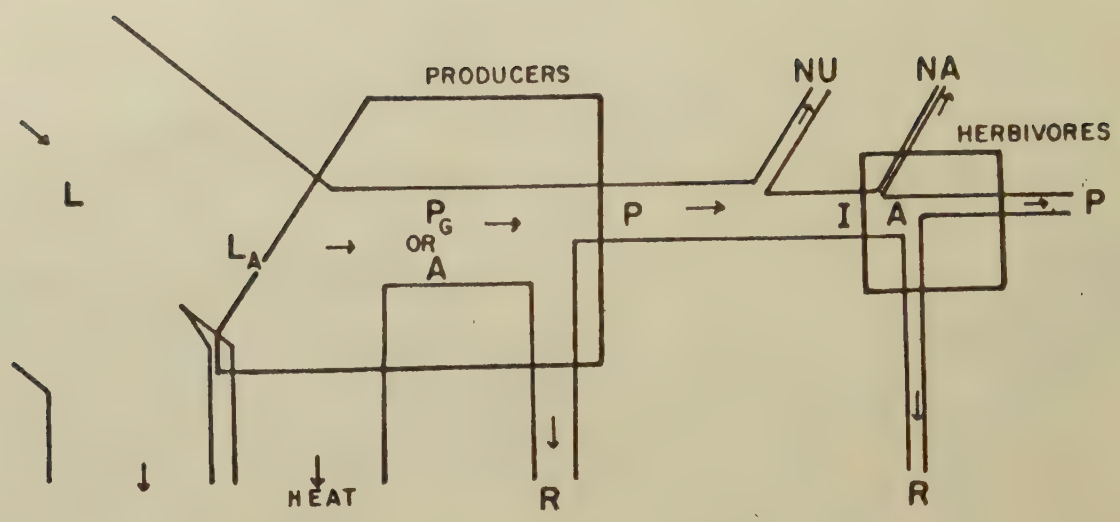


Fig. 6.2 Simplified example of a marine ecosystem. Energy flow shown by open arrows



Ratio	*Designation and Explanation*
A. Ratios Between Trophic Levels	
$\frac{I_t}{I_{t-1}}$	Trophic level energy intake (or Lindeman's) efficiency. For the primary level this is $\frac{P_a}{L}$ or $\frac{P_a}{L_A}$
$\frac{A_t}{A_{t-1}}$	Trophic level assimilation efficiency
$\frac{P_t}{P_{t-1}}$	Trophic level production efficiency
	For the primary level P and A may be in terms of either L or L_A as above; $A_t/A_{t-1} = I_t\ I_{t-1}$ for the primary level, but not for secondary levels.
$\frac{I_t}{P_{t-1}}$ or $\frac{A_t}{P_{t-1}}$	Utilization efficiencies
B. Ratios Within Trophic Levels	
$\frac{P_t}{A_t}$	Tissue growth efficiency
$\frac{P_t}{I_t}$	Ecological growth efficiency
$\frac{A_t}{I_t}$	Assimilation efficiency

Fig. 6.4 Various types of ecological efficiencies. Symbols are as follows (see diagram): L = light (total), L_A = absorbed light, P_G = total photosynthesis (gross production), P = production of biomass, I = energy intake, R = respiration, A = assimilation, NA = ingested but not assimilated, NU = not used by trophic level shown, t = trophic level, t-1 = preceding trophic level (from Odum, 1959)

7. THE AQUATIC ENVIRONMENT

7.1 Introduction

The study of the aquatic environment is a vast subject which includes investigations of its physical, chemical and biological components and of how these vary in both space and time. Only the main outlines of study are described in this section. Despite the fact that the aquatic environment, particularly the sea, has been studied intensively, few relationships between fish and their environment have been established which are useful to fisheries biologists. This is probably because the environment is complex and the fish's reactions to it not straightforward, so that simple relationships, for example, between year-class strength and water temperatures, can seldom be expected.

Both for this reason and also for the reason that no single laboratory can undertake to study all aspects of this subject, the director of a laboratory engaged in practical fisheries research must decide what work will give useful results. The decisions will be made on the basis of what aspects of environmental work in either the same or other regions have been shown to be of real value.

Two potentially useful studies are the distribution of fish in relation to environmental features and the basic productivity of the water and its relation to the potential productivity of the water masses. This section will concentrate mainly on these studies.

7.2 Planning the sampling programme

Sampling programmes must be planned. The pattern of observations required must be drawn up as a station list. A station is defined as a geographical point at which observations are carried out. There are some principles in station planning which are generally applicable: (a) lines of stations (sections) should run at right angles across the expected isolines of the characteristics to be sampled (an isoline is a line along which the characteristic studied e.g. temperature is the same); (b) the distance between stations should be governed by the expected rate of change along the section of the properties to be measured; (c) the frequency of sampling should be related to the expected rate of change with time. The distance between stations should be governed by the expected rate of change in the characteristic being sampled; the greater the expected rate of variation the less distance there should be between stations. In the sea there are standard depth observations which are suitable under most circumstances. These are 0, 10, 20, 30, 50, 75, 100, 150, 200, 300, 400, 500, 600, 800, 1,000, 1,200, 1,500, 2,000 m and at 1,000 m intervals thereafter, where applicable.

Having decided the number of stations and the frequency with which they are to be sampled sufficient equipment, chemicals and sample containers must be put on board.

At sea the person with most navigational experience, usually one of the watch-keeping ship's officers sees that the ship is precisely at the position of the station decided beforehand by the scientist. This is recorded by the latter together with details of the observations made.

7.3.1 Temperature observations

Temperature is the physical characteristic of the environment most widely recorded because it is easy to measure and because it has proved the environmental feature most easily related to fish distribution and aggregation. The easiest way to take a surface water temperature is to fill a bucket with water from the lee side of the ship, away from any cooling water or other outfalls and then read the temperature with a small heat-capacity thermometer.

However, special equipment is required for taking temperatures at depth. The same equipment is often also used for taking water samples.

Pettersen-Nansen bottles (Fig. 7.1) are probably the most convenient sampling instrument in depths up to 200 m. They should not be used below this depth because temperature changes can take place while hauling them from greater depths. Using a single Pettersen-Nansen bottle the temperature at each depth to be sampled is obtained by successively lowering the bottle to each depth, closing it with a messenger (a weight slid down the wire) after it has been at that depth for at least half a minute, and retrieving it. The temperature is then read immediately using a thermometer magnifier.

At depths greater than 200 m temperatures are taken with thermometers fitted in either a reversing frame or attached to reversing water sampling bottles (Fig. 7.1). Up to seven bottles or frames can be used at one time, spaced on the wire to take samples from the required depths. The first is activated by a messenger, which then releases the next messenger and so on. Thermometers are used in pairs, one protected and one unprotected, and often two sets are used, one checking on the other.

A protected thermometer is so called because it is encased in a sealed glass tube which protects it from being squeezed by the pressure of the water. (Fig. 7.2) The unprotected thermometer has no such protection and the pressure of the water squeezes the glass and makes the temperature of the unprotected thermometer read higher than that of the protected. Because the pressure of the water is proportional to depth the true depth at which the sample was taken can be calculated.

A rough estimate of this can be obtained from the angle of the wire to the vertical and the length of wire out. This is satisfactory for wire angles of 5° to several hundred meters but only to 100 m for larger wire angles. The reasons for the differences between calculated depth and actual depth are that the wire does not run in a straight line from the ship to the sampling bottle and that the speed of the currents alters the angle of the water. If current systems overlay each other, running in directions, the wire angle will change appropriately as it runs through them.

The main thermometer has a special construction. It consists of a main expansion bulb (Fig. 7.2) and a smaller one at the other end of the tube. The capillary of the tube has two constrictions (Fig. 7.2). The thermometer is lowered with the main bulb lowermost and the mercury in the main bulb expands to fill the capillary and part of the smaller expansion bulb. When the messenger hits the bottle and reverses the frame the mercury column breaks at the lower constriction leaving a column of mercury which is now isolated from the main expansion bulb and whose volume was dependent upon the temperature at the sampling point. The volume of this mercury and therefore the temperature which is recorded will still depend upon the temperature at which the main thermometer is read so each main thermometer has an associated auxiliary thermometer to record this (Fig. 7.2). The main thermometers are read to an accuracy of 0.01°C and the auxillary thermometer to 0.1°C, usually with a special reader incorporating a light and a magnifying glass.

When taking a series of temperature observations (known as a 'cast') the bottom bottle is lowered to its correct depth and held there for at least five minutes to allow each thermometer to attain the temperature of the layer which it is intended to register. The first messenger is then released to close the first bottle. The closure of this and subsequent bottles should be checked by holding the wire, each closure being indicated as a 'thump' on the wire. Beyond about 500 m these thumps may not be felt and the messenger should be timed; it travels at a rate of 250 m a minute. When the bottles are retrieved they must be kept vertical, in the reversed position, until the temperatures of all the thermometers have been read. After reading they should be stored with the bulb down, to reduce the danger of air-lock formation in the thermometers.

A series of corrections has to be made to the temperature as read on the protected thermometer to obtain the temperature at the point where the sample was taken. These corrections are to allow for

(a) expansion or contraction of the recording column of mercury resulting from differ-

ences between the temperature at the point of sampling and that at reading as already described

(b) slight irregularities in the capillary tube called the 'index correction'; this is obtained by calibrating the thermometer at different temperatures. Most of them have been calibrated by the U.S. Bureau of Standards, the N P.L., or P.T.R. which supply with the thermometer certificates giving the index correction to be made at different readings of the thermometer.

The volume of the main thermometer bulb up to the reading of 0°C on the capillary, known as the degree volume, must also be known. It is given on each thermometer. The total correction to be made to the temperature read on the thermometer is given by:

$$\Delta T = \frac{(T^1 + V_o)(T^1 - t)}{K - (T^1 + V_o) - (T^1 - t)} + I$$

in which ΔT = the correction
T^1 = temperature read from the protected reversing thermometer
t = temperature read from the auxiliary thermometer associated with the protected reversing thermometer
V_o = volume of mercury below 0°C mark at 0°C, expressed in degrees centigrade (= the degree volume)
K = reciprocal thermal coefficient of expansion of the thermometer system
I = index correction for errors in the thermometer scale

V_o, I and K are constants which are supplied with the thermometer. As K is usually 6,100 or 6,300 and the sum of the other terms approximately 100, the required degree of accuracy (0.01°C) can be obtained using the following formula:

$$\Delta T = \frac{(T^1 + V_o)(T^1 - t)}{K - 100} + I$$

which is the formula normally used.

$$T_w = T^1 + \Delta T$$

in which T_w is the corrected reading of the protected thermometer.

The formula for correcting the temperature of the unprotected thermometer is:

$$\Delta T_u = \frac{(T_u{}^1 + V_o)(T_w - t_u)}{K} + I$$

in which $T_u{}^1$ = temperature read from the unprotected reversing thermometer
t_u = temperature read from the auxiliary thermometer associated with the unprotected reversing thermometer

and V_o, K and I are the same constants as above but are the values for the unprotected reversing thermometer.

$$T_u = T_u{}^1 + \Delta T_u$$

in which T_u is the corrected reading of the unprotected thermometer.

The depth, in metres, at which the temperature was taken (D), called the thermometric depth, is given by:

$$D = \frac{T_u - T_w}{Qd}$$

in which Q = pressure coefficient of the unprotected thermometer
d = mean density of the sea water column above the depth at reversal

and the other symbols are as previously described.

Q is a constant supplied with the thermometer and d is obtained from tables.

Full details of these formulae and of the methods of processing temperature data are given by LaFond (1951).

A worked example is given in Appendix 7.1.

In many cases it may be advisable to record sea surface temperatures at frequent intervals when the ship is underway because rapid changes usually indicate current divergences and convergences which may be of importance in fish distributions. The surface temperature can be easily measured by taking a sample in a bucket or, in larger ships, by using a thermograph fixed to the condenser intake. The latter gives a continuous record.

Continuous recording of the temperature-depth profile is made with a bathythermograph (Fig. 7.3) which records temperature against depth on a smoked glass slide. It can be either lowered when the ship is stationary or whilst it is underway. The bathythermograph is lowered into the surface water and kept there for 30 seconds to allow the thermometer to adjust to the surface temperature before lowering to the required depth. The amount of wire required to reach any depth will depend on the ship's speed and the wire characteristics. It is normally advisable to do several trial runs to get a wire/depth conversion factor. The surface temperature should also be read with a bucket and thermometer when the bathythermograph is lowered. After retrieving the instrument the slide is preserved by marking it with the necessary identification data, washing it with freshwater, dipping it into amyl-acetate lacquer and then drying it in a rack. Bathythermograph records are read by placing the slides over a standard grid in the viewer provided with the instrument. The actual temperatures are not read so accurately as with a thermometer, the expected precision being normally about 0.1°C. Bathythermographs provide a continuous record of temperature against depth which is obtained quickly and which, for many purposes, more than compensates for the reduced accuracy. Expendable bathythermographs are now available; these are fired from the ship's side while it is in motion and the temperature-depth record is transmitted back to the ship by wire which automatically disconnects at the ship when all of it has paid out.

Bathythermographs are particularly useful in providing an exact measure of both the depth and the intensity of the thermocline. This is an area of marked temperature discontimuity providing a physical mechanism which separates two layers of water. The water below the thermocline may be de-oxygenated and uninhabitable by fish. In some lakes, such as Lake Kivu, the thermocline is permanent and the lakes always stratified. In freshwater the change in density with temperature is much more important than in sea water, particularly at temperatures above 20°C.

7.3.2 Application of Temperature Data

Temperature data find an application to practical fishery problems mainly where the range of distribution of a species is limited by oceanic boundaries or where a species aggregates at these boundaries. Examples of these phenomena are broadly divisible into three categories, those in which:

1. isotherms limit the geographic range of a fish species

2. fish aggregate against a current boundary, either mechanically because of the aggregation of food at the boundary

3. fish concentrate in areas of upwelling or divergence.

Perhaps the best example of the first category is the distribution of Barents Sea cod, which is limited by the 2°C isotherm. In early summer, when only a small area of this region is covered by bottom water warmer than 2°C, cod are found concentrated in this warmer water and catch-rates there can be high (Fig. 7.4). Later in the summer, as the warmer water spreads eastward, the cod spread out over this wider area of higher temperatures and catch-rates fall (Fig. 7.5).

There are several examples in the second category. King and Hida (1957) have shown that yellow-fin tuna aggregate in zones of both convergence and divergence of the Pacific equatorial currents and that in these zones, when the divergence is narrow, catches are 2 to 3 times higher than in the main currents (Fig. 7.6). Similarly it has been shown that Atlanto-Scandian herring concentrate at the sharp temperature boundary between warm and cold water off the east coast of Iceland during the summer (Benko and Seliverstov, 1971). In the eastern North Sea in spring, herring are packed on the western edge of the cold Baltic outflow where it meets the warmer North Sea water. In such cases the association between fish aggregation and temperature is probably not direct. In the case of the North Sea herring, the cold low salinity water flowing out of the Baltic provides vertical stability, which in turn leads to an earlier spring outburst of phytoplankton and zooplankton than over the rest of the North Sea. It is probably the high level of food availability in this area, rather than the temperature directly, which results in the herring aggregating. Similar mechanisms may apply in the other cases cited.

The third category, of fish concentrating in areas of upwelling, is best illustrated in the fisheries for anchoveta off the coast of Peru and northern Chile and in the pilchard fisheries off the west coast of Africa. In both cases the fisheries take place in areas where currents well up against the continental shelf, resulting in areas of very rich feeding. Again the association between temperature and fish in these cases is probably an indirect one with food as the direct link.

Quite apart from the circumstances which permit temperature data to be used to predict the areas of highest concentrations of fish and of most profitable fishing, temperature has a direct effect on the metabolism of the fish. Fish can only tolerate temperatures within a certain range and within this range there is a narrower optimum range for growth and reproduction. Normally, in areas where a fish species has been established for a considerable time the temperature will not depart from the tolerance range of the species but variations of temperature outside the optimum range for reproduction can result in variations in the success of recruitment. At West Greenland the cod fishery did not exist before the 1920's because the water was too cold for cod. Now it seems as if the water is again becoming too cold. Year-classes since that of 1968 have been very small and it is doubtful whether the stock will continue to exist.

In the literature there are numerous references to the effects of variations in temperature altering the timing of and the success of spawning. Mankowski (1950) states that low temperatures delay, and high temperatures advance, the spawning of Baltic cod. Simpson (1953) has shown that abnormally low temperatures on the spawning grounds forced North Sea plaice to spawn elsewhere. Woodland (1964) and Galloway (1941) describe the lethal effects of low temperature on fish.

Success of egg and larval survival, as measured by variation in year-class strength, would be expected to show the greatest change with temperature because it would seem that at these stages the species would be most susceptible to departures from the optimum temperature requirements. Kurita (1959) has related variations in year-class strength of Japanese sardine to temperature variations. Chase (1955) has done a similar relationship for Georges Bank haddock, Benko and Seliverstov (1971) for Atlanto-Scandian herring and Postuma (1971)

for North Sea herring. There are numerous instances of similar relationships in the literature for a large number of species in many sea areas. But the fact remains that all of these are retrospective correlations with considerable latitude for the original choice of the temperature variable. That the relationships are seldom heard of again, after initial publication, might suggest that their predictive value is small.

There is little direct evidence of mortality associated with abnormal temperatures, either in the adult or larval stages. Galloway (1941) has recorded extensive mortality of fish in the coastal areas of Florida associated with drastic temperature changes whilst Simpson (1953) for the cold winter of 1946-47 recorded mortalities of sole, cod and whiting in the southern North Sea.

7.2.3 Chemical sampling

Detailed descriptions of the methods of analyses for the wide range of substances in water for which analyses can be carried out are given in the FAO Manual of Methods in Fisheries Biology and in standard textbooks quoted there (e.g. Strickland and Parsons, 1960). In this manual only advice on how samples should be taken and preserved for analysis of the major substances will be described and some of the more important applications of these analyses discussed.

Generally water samples for chemical analysis are taken from either the same or a selection of the stations and depths sampled for temperature. To take samples a piece of rubber tubing with a glass tube about 15 cm long in one end is fastened to the tap of the sampling bottle, the air valve at the top of the bottle is opened and water drawn off. Samples for oxygen determination, if required, are taken first, followed by those for other chemical analysis. The bottles in which the samples are to be stored are first rinsed with a little of the sample water before filling with the sample. Chlorinity analysis is one of the most important in the marine environment. The results are used for deriving the salinity and density of the water which in turn are used for the characterization of water masses and for tracing their origin, movements and mixing. Salinity variations in offshore areas are relatively small but can be considerable in coastal areas due to variations in run-off. These variations can affect the osmotic balance of fish and the buoyancy of pelagic fish eggs.

Dissolved oxygen samples are run into 250 ml dark bottles of accurately known volume fitted with ground glass stoppers. In drawing off the sample the glass tube must be kept close to the bottom of the sample bottle to ensure that no bubbles of air enter the sample, and the water allowed to flow after the bottle is full. The tube is withdrawn and the glass stopper fitted when the bottle is completely full, care being again taken that no air bubbles enter the bottle with the stopper. If these precautions are not followed oxygen from the air will dissolve in the sample and result in a false determination. To fix oxygen samples, 1 ml manganese chloride solution is added near the top of the sample bottle, followed by 2 ml of alkali iodide mixture added by immersing the tip of the pipette to about one inch below the surface. The stopper is replaced immediately and the chemicals mixed very thoroughly for at lease fifteen seconds during which the stopper must be held firmly in place.

In the sea low oxygen content seldom is critical for the survival of fish but this can occur in certain localities in the tropics, where a subsurface oxygen minimum layer is formed, and close to the bottom of badly aerated depressions, such as the deeper layers of the Black Sea. Oxygen depletion is much commoner in fresh water, instratified lakes and some marshes. Because oxygen is produced by plants in photosynthesis the oxygen content of the water can also give a useful, if rather rough, indication of the amount of carbohydrate synthesis which has recently taken place in that body of water.

Salinity samples are run into 200-300 ml bottles fitted with attached stoppers with rubber washers. The bottles are almost completely filled, leaving only 5-10 ml space under the stopper to allow for expansion. These samples require no other treatment before analysis.

Phosphates, nitrates and silicates are important nutrient salts, whose exhaustion in water limit organic production. The amounts of these nutrients in an area indicate the potential fertility of an area and of the biological processes which have taken or are taking place. Samples for phosphate determination are drawn off to fill the bottle to 2 cm below the stopper. Six drops ($\frac{1}{2}$–1 ml) chloroform are then added, the stopper put on and the bottle shaken vigorously until the sample becomes milky. The samples are then stored in a refrigerator and analysed at the earliest opportunity.

Nitrate samples are drawn off into small bottles with ground glass stoppers, leaving ample space to allow for expansion. These samples are stored without chemical treatment in a deep freeze until analysis. Silicate samples are stored in small plastic bottles and kept in a refrigerator, without preservation, until analysis.

Further details on sea water analyses are given by Strickland and Parsons (1960).

7.3.4 Light intensity

Measurement of light intensity at different depths is valuable because it is related to both the photosynthetic activity of the plants, which provide the primary production, and the ecology and depth distribution of the animals. The diurnal vertical migration of many marine organisms suggests that they are following an optimum light intensity. Moreover, the reaction to fishing gear of some species is partly governed by their ability to see it, and this will depend upon the light intensity at the depth they occupy. Generally, light energy at different depths in the sea is not measured directly but is computed from measurement of the extinction coefficient of the water and the intensity of radiation at the surface. The extinction coefficient can be measured either visually or with optical instruments. The simplest visual method is the Secchi disc which is a white disc 20 cm in diameter. It is lowered into the water on the shadow side of the vessel attached to a wire. The depth at which it disappears from sight is measured in meters. It is lowered 2–3 m deeper and then hauled to the surface, the depth at which it becomes visible again also being noted. The mean of these two depths is converted to an extinction coefficient from the equation $X = 1.7/D$, where X = extinction coefficient and D = the mean depth of disappearance of the Secchi disc in meters. The extinction coefficient can also be measured by extinction meters which have an electrical light 60–200 cm above a photocell.

7.3.5 Pollution

Although pollution is a growing problem, particularly in seas surrounding highly industrialized countries, it is not included in this manual for two reasons. First, the efficient monitoring of both heavy metals and toxic organochlorides demands a level of expertise and sophistication of equipment, which is the subject of special publications. Second, there is no evidence to date of any direct effect of pollutants on the productivity of any marine fish stock except for isolated incidents close to a source of pollution. There is considerable evidence that pollution can seriously affect the suitability of fish as food (Ackefors et al., 1970) but this is a problem for public health authorities rather than for the marine biologist.

7.4 The Biotic Environment

Because the field of plankton investigations is so extensive it is not covered in detail in this manual, except for two aspects which have the most direct application to practical fishery problems. These are firstly the assessment of primary production and total plankton biomass, which are guides to the potential capacity of an area to support fish stocks, and secondly the application of fish egg and larval surveys to investigate the time and place of spawning of fish and in fish stock assessment.

7.4.1 Phytoplankton Standing Crop and Primary Production

The simplest and most accurate method of estimating the gross production of an area is to measure the photosynthetic pigments of the plant population. The rate of photosynthesis

is then calculated from the chlorophyll concentrations, light and transparency data using a general relationship between light and the rate of photosynthesis. This gives a value for gross production only; to estimate net production a value for the loss due to respiration is required, and this is more difficult to obtain. However, for most practical fishery purposes values of gross production are quite adequate.

The technique consists of taking a sample of 1 to 5 l, depending on the richness of the phytoplankton, from a number of depths within the photosynthetic zone using a Pettersen-Nansen or other suitable water bottle. These samples are then filtered through cellulose membrane filters of 0.4-0.65 um, (um, pronounced mu-em, is 10^{-6} metres) pore size which have been covered with sufficient finely powdered $MgCO_3$ to give about 10 mg/cm^2 over the area of the filter. A suction pressure of 2/3 atmospheres applied to the filters speeds up filtration. These filters can be stored, in the dark, over silica gel at 1°C for up to two months, although it is preferable to extract the pigment from the damp filter immediately, and carry out the spectrophotometric measurement without delay.

The pigment is extracted from the phytoplankton by placing the filter in 90% acetone for at least 10 minutes. Extracts should preferably be treated immediately, but can be stored for several hours at room temperature in the dark. Measurement of the pigments is carried out using the spectrophotometer, with a bandwidth of 3 um or less and cells with a light-path of 4-10 cm, reading the extinction at 750, 663, 645 and 630 um against a 90% acetone blank. The extinction at 750 um is then subtracted from those at the other values and the answers divided by the light-path of the cell used in centimetres. If these corrected extinctions are e_{663}, e_{645}, and e_{630} the concentration of chlorophyll *a* in the 90% acetone extract is = $11.64e_{663}-2.16e_{645}+0.10e_{630}$. If this value is then multiplied by the volume of the extract in cubic millimetres and divided by the volume of the sea water filtered in litres, the concentration of chlorophyll in the sea water is obtained as ug per litre. A full account of the techniques for the determination of plant pigments in sea water is given in "Determination of Photosynthetic Pigments in Sea Water", Monograph on Oceanographic Methodology, Unesco 1966.

The concentration of chlorophyll *a* calculated as given above, gives an adequate measure of the standing crop of phytoplankton. If an estimate of gross production is required in terms of weight of carbon produced per day this can be calculated from the equation

$$P = 3.7\frac{R}{K}C$$

where P = photosynthesis in g carbon/m^2/day

R = relative photosynthesis

as given in a graph in Ryther and Yentsch (1957) which relates relative photosynthetic activity to surface radiation for the appropriate value of surface radiation. K is the extinction coefficient per meter measured as described on page 159 and C = g chlorophyll per cubic meter.

7.4.2 Zooplankton Biomass

One of the major problems in measuring zooplankton biomass is that no one gear is adequate for sampling the wide size range of organisms which occur in the plankton, ranging from protozoa of about 2u to coelenterates up to 1 metre in diameter. In principle this difficulty could be overcome by using several gears at each station to cover all the major size groups. However, there would then be considerable overlap in the size ranges sampled by the different gears so that when the catches from them were summed to give the total biomass some organisms would be counted more than once. In this situation the best solution is probably to adopt a single gear which gives adequate sampling of the size range of organisms which constitute the bulk of the plankton biomass and accept the fact that the estimate is an underestimate because a proportion of the plankton has been omitted due to mesh selection or evasion.

A zooplankton net with a mesh aperture of 200 μm is the best compromise and a suitable net of this mesh size has been described in detail by Working Party 2 of the ICES/SCOR/UNESCO Working Group (Anon., 1968) which was set up to advise on the standardization of zooplankton sampling. The Working Party recommended that this net should be used for vertical hauls but there seems no reason why it should not be used obliquely if it is towed at about 1.5 knots. However, this is too slow for larger organisms, which will evade the net at this speed. For pelagic decapods and larval fish in the later stages speeds of 4 knots are necessary.

The depth range which it is necessary to sample to measure the zooplankton biomass can be determined only by experiment locally. However, samples taken by either oblique or vertical hauls from a maximum depth of 200 metres to surface will usually give a sufficiently accurate estimate of the zooplankton biomass. The question of the relative merits of vertical and oblique hauls for measuring the abundance of plankton has not been fully resolved. Vertical hauls have the advantage that the volume of water filtered is more easily measured but on the other hand they are very susceptible to the variation produced by small scale plankton patchiness. On balance, it would seem that a more valid estimate is given by oblique hauls because they largely even out plankton patchiness and so give a better average estimate representative of a fairly large area. The meshes of plankton nets will clog if plankton, either phytoplankton or zooplankton, is dense. For this reason plankton nets should always be fitted with flowmeters so that the volume of water filtered can be calculated.

Two sampling instruments are the Gulf III (Fig. 7.7) and the Bongo sampler (Fig. 7.8) which can be towed obliquely. They are fitted with filtering cones of 250 μm mesh aperture. Zooplankton samples should be preserved in 4% formalin buffered with either borax or marble chips. To determine the biomass of the sample, the simplest method is to measure the displacement volume by filtering the sample through a piece of fine bolting silk (No. 25). The piece of silk and the retained plankton are then placed on an absorbent paper for 10 minutes after which the sample is put into a graduated cylinder containing a known volume of water. The increase in volume in the cylinder is recorded as the displacement volume of the plankton. The biomass weight (wet weight) can be obtained by transferring the collection to a glass cylinder of known weight which has a base of fine nylon mesh. When the bulk of the preservative has drained off a suction pump is used to remove the remainder. The material is then washed with water under suction, which is continued for a short time to draw air through the plankton before weighing. The results of such estimations are expressed as weight or volume below 1 m^2 of sea surface from the volume of water filtered by the sampling gear as measured by flow-meter and the depth through which the sampling gear was hauled.

Although these methods give the most accurate and comparable results, useful information can be obtained by towing simple zooplankton nets. If a flow-meter is not used the results are not quantitative but if a standard procedure is followed each time the results are qualitatively comparable. An example of a qualitative study of this type is that by Holden and Green (1960).

The weight of the plankton biomass would be expected to be of greatest relevance to fishery problems in two major spheres. For those pelagic fish species which feed directly on the plankton, a relation might be expected between centres of high zooplankton abundance and concentrations of fish and so of high catch rates. Although in general terms this has been shown to be true for a number of fish species the detailed relationship is normally far from simple and its value as a method of guiding a fishing fleet to the most productive grounds would seem very limited. Two reasons may account for this: first, there may be a time lapse between the build-up in the plankton and the aggregation of the fish on to it; secondly, the areas of highest fish aggregation are probably those where no plankton occurs because it has all been eaten.

The other area in which zooplankton estimation would appear likely to give useful practical fishery results is in prediction of year-class strength. The most widely accepted hypothesis is that the variations in year-class size of the highly fecund teleost fishes

result from changes in the amount of available food from year to year, lack of adequate food being held to be the main factor causing mortality of larval fish. Although this seems acceptable on theoretical grounds (Gulland, 1965), the concept raises some problems of interpretation in species which do not show a similar pattern of year-class strength variation (Jones, in press), but which spawn in the same area at the same time and have similar food preferences. Certainly it is true that no one has yet succeeded in showing a convincing long-term relationship between year-class size and the abundance of food for any species. This may be due to the inadequacy of the available data rather than to the underlying premise being untenable.

7.4.3 Fish Egg and Larval Surveys

The other major application of plankton sampling in practical fisheries problems is that of accurately assessing the time and place of spawning and the size of the spawning stock. The timing can be assessed from an examination of the spawning cycle, as discussed in Section 5. It may be possible to determine the area of spawning from the position of capture but fish may remain in a high maturity stage for a considerable period of time before spawning, during which they may move a considerable distance. A more accurate technique is to survey the area for the presence of eggs or larvae of the species under consideration by plankton sampling. Before such a survey as much information as possible about the time and place of capture of fish in spawning condition should be obtained. Use of these data will allow the area and time span of the survey to be reduced to the minimum.

An ACMRR Working Party on Fish Egg and Larval Surveys has recommended that for sampling fish eggs and larvae, other than the larger sizes of the latter, the best available instrument is a 60 cm Bongo Sampler. This is fitted with nets of 0.505 and 0.333 mm mesh size and towed obliquely at from 1.5 to 2.0 knots from the maximum depth at which the eggs and larvae of the species under investigation are found to the surface (Anon., 1971). These speeds are satisfactory for eggs and early larvae which cannot escape the nets. Higher speeds (up to 4 knots) are required to catch late stage larvae. An FAO Manual for fish egg and larval surveys is in course of preparation. Such surveys should be done over a grid of stations, at fixed distances apart, covering the whole of the area which from other data available may contain spawning centres. Similarly, such grids should be repeated at regular time intervals over the total period which again from other sources of information may contain spawning activity.

Before starting egg and larval surveys it is best if the planktonic stages of the species being investigated can be identified so that there is no possibility of confusion with another species with closely similar eggs and larvae. If two species, whose eggs are extremely difficult to separate in the earliest stages, spawn in the same area about the same time a later stage of development which can be definitely allocated to each species must be used. This will introduce some error because the eggs will have drifted from the spawning area and dispersed over a wider area than they initially occupied during the period from spawning to the stage utilized. Similarly, unless the time taken from spawning to the development stage used is known, there will be a bias in the estimate of the start, finish and time of maximum spawning activity.

In the early stages of a fishery when the egg and larval stages have not been identified there may be no option but to group eggs and early larval stages by species. Identification can be done only by rearing eggs and larvae in the laboratory, which is not easy.

The estimation of the abundance of a fish stock from egg and larval plankton surveys makes similar demands to those of the identification of time and location of spawning. The basic concept of assessing stock abundance in this way is comparatively simple. The total production of an egg or larval stage of a species is obtained from a series of surveys covering a spawning season. From a knowledge of the mean fecundity of mature females the total abundance of the mature female stock can then be calculated from the equation:

$$M = \frac{P}{F}$$

where P = egg production estimate

F = mean fecundity of mature females

The abundance of the exploited stock is obtained from the proportions in the commercial catches of mature female fish to that of mature male and immature fish combined. Since the fecundity of a fish is proportional to its weight, the stock can also be estimated in weight by using the fecundity per unit weight relationship rather than the mean fecundity.

The main problem is to obtain an estimate of egg production over a spawning season. This is done by sampling over the area of distribution of the eggs sufficiently intensively to give an adequate representation of changes in egg density. Normally the total egg counts for each survey are obtained by sampling a grid of stations regularly placed at fixed distances apart. This simplifies the subsequent computation. For maximum efficiency of estimation there is much to be said for sampling at closer distances in the areas of highest concentration, where the variability is normally highest, and at more widely spaced stations at the fringes of the distribution where variability is normally least. It is necessary to sample the total range of depth within which the eggs are distributed by oblique hauls with a Gulf III or Bongo net. This must be fitted with a flow-meter so that the total number of eggs caught can subsequently be converted to the number below 1 m^2 of surface. The numbers caught at each station are then converted to numbers in the total volume of distribution; for a regularly spaced station grid the mean of the station observations is multiplied by the volume which each station represents; for an irregularly spaced sampling grid isometric lines are drawn, the volume within each isoline measured and this volume multiplied by the number of eggs.

Because egg production varies with time over a spawning season, it is necessary to carry out a number of surveys during the spawning season. To obtain estimates of daily egg production, the total production for each survey is divided by the number of days which it takes for the egg to pass through the stage utilized in the analysis at the temperatures prevailing at the time of that survey. The final result is a series of estimates of the total daily egg production at various times during the spawning season. To obtain the total seasonal production there are two approaches. For many species egg production over a season follows a normal curve; the area under this type of curve can be estimated from a knowledge of the values at any three points on it. Of course in the initial stage of the investigation it is necessary to carry out more than three cruises to determine whether the seasonal egg production is normal.

If the seasonal egg production does not follow a normal curve an estimate of total production is obtained in two ways. One method is to take the total egg production for the cruise and to weight this as follows. Let:

P = total egg production for the survey
d = duration of the survey in days
2b = the number of days between this survey and the preceding survey
2c = the number of days between this survey and the next survey

Then the estimated egg production for the period (b+c+d) days is:

$$\frac{P\,(b + c + d)}{d}$$

For the first and last surveys the egg production should be low and for the first survey b can be taken as zero and for the last survey d likewise. The other method is to plot the survey totals as ordinates against the mid-date of that cruise and to measure the area under the resulting curve. If the curve of seasonal spawning intensity is not normal more surveys will be required to give comparable accuracy than if it is normal. The number required

cannot be defined until a pilot survey has been run to determine how spawning does vary with time. A discussion of the use of such surveys to estimate stock size and the confidence limits of such estimates is given in Saville (1964).

Example:

Nine surveys were carried out in March 1971 to sample the abundance of haddock eggs. During each survey 32 stations were sampled, the stations being spaced 20 nautical miles apart in a square grid pattern.

(a) During the survey 10-12 March the required data for each station were as follows:

Station Number	Number of eggs in Stage I in each sample A	Volume of water filtered (cubic metres) B	Depth of haul (metres) C	Number of Stage I eggs below 1 sq metre AxC/B=D
1	0	55	10	0.00
2	1	62	31	0.50
3	1	58	42	0.72
4	0	65	63	0.00
5	1	70	64	0.91
6	8	63	63	8.00
7	10	61	42	6.89
8	4	62	31	2.00
9	2	60	20	0.67
10	25	54	30	13.89
11	40	58	40	27.59
12	1	45	45	1.00
13	0	50	52	0.00
14	15	63	45	10.71
15	75	65	47	54.23
16	0	60	25	0.00
17	0	61	21	0.00
18	90	58	36	55.86
19	35	56	48	30.00
20	1	63	63	1.00
21	0	61	58	0.00
22	75	60	43	53.75
23	15	59	40	10.17
24	1	57	22	0.39
25	0	66	30	0.00
26	10	65	38	5.85
27	20	75	50	13.33
28	0	57	61	0.00
29	0	59	83	0.00
30	2	50	75	3.00
31	1	65	62	0.95
32	0	53	71	0.00

Eggs pass through Stage I in 2.5 days. Calculate the mean daily egg production within the area surveyed during the time this survey was carried out (1 square nautical = 343 x 10^4 square metres).

The mean number of eggs per square metre in the area surveyed from the data in column D = 9.45.

Mean daily egg production = 9.45/2.5 = 3.77 per square metre.

Each station represents 20^2 square nautical miles

∴ Area of survey = 400 x 343 x 10^4 x 32 square metres
= 43904 x 10^6 square metres

∴ Total daily egg production during period of this survey
= 43904 x 3.77 x 10^6 = 165518 x 10^6

(b) Other surveys carried out over this area in 1971 gave the following estimates of daily egg production:

Period of Survey	Estimated Daily Egg Production
3–5 March	3290 x 10^6
6–8 "	49106 x 10^6
10–12 "	165518 x 10^6
13–15 "	212086 x 10^6
16–17 "	243750 x 10^6
19–21 "	175208 x 10^6
23–25 "	83690 x 10^6
26–28 "	22115 x 10^6
29 March–1 April	925 x 10^6

Calculate the total annual egg production of the stock.

Plot these values against the mid-date of each survey as in Figure 7.9 on an appropriate scale

The area under the graph is equal to 153.25 large squares.

Each of these represents 2 x 1 x 10^{10} eggs on the scale used

∴ Total annual egg production = 153.25 x 2 x 10^{10}
= 306.5 x 10^{10}

(c) The fecundity–length relationship of this stock is $F = 1.309L^{3.2}$ where F = fecundity and L = length of a female in centimetres.

If the mean length of the spawners is 28 cm and the sex ratio of ripe fish is 1:1 calculate the number of fish in the mature stock.

The mean fecundity of the female mature stock is = 1.309 x $28^{3.2}$
= 55,973

$$\therefore \quad \text{Size of mature stock} = \frac{306.5 \times 10^{10}}{55973} \times 2$$

$$= 10.95 \times 10^7$$

Similar techniques have been used for species which lay their eggs on the bottom; grab samples are taken over the spawning beds and the area contoured. However, there is no suitable technique for sampling freshwater fish, the majority of which attach their eggs to plants. Also the larvae are not distributed in a pelagic place as are those of marine fish.

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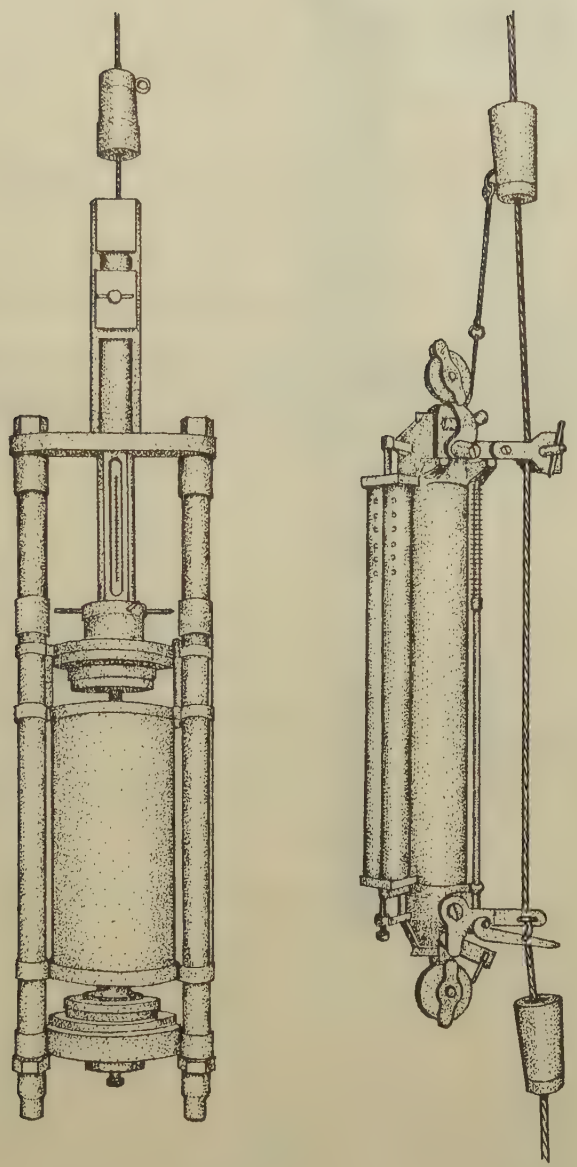


Fig. 7.1 Pettersen-Nansen (left) and reversing water bottle (right)

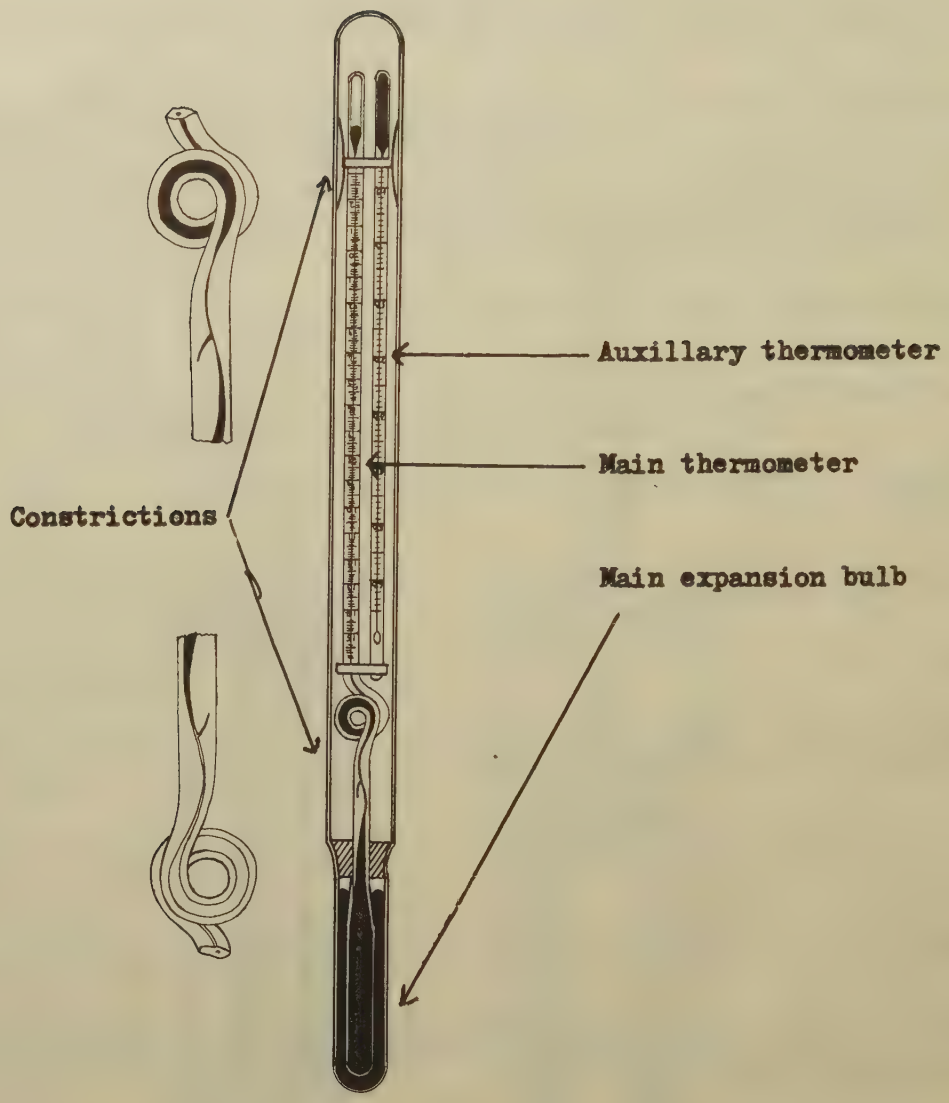
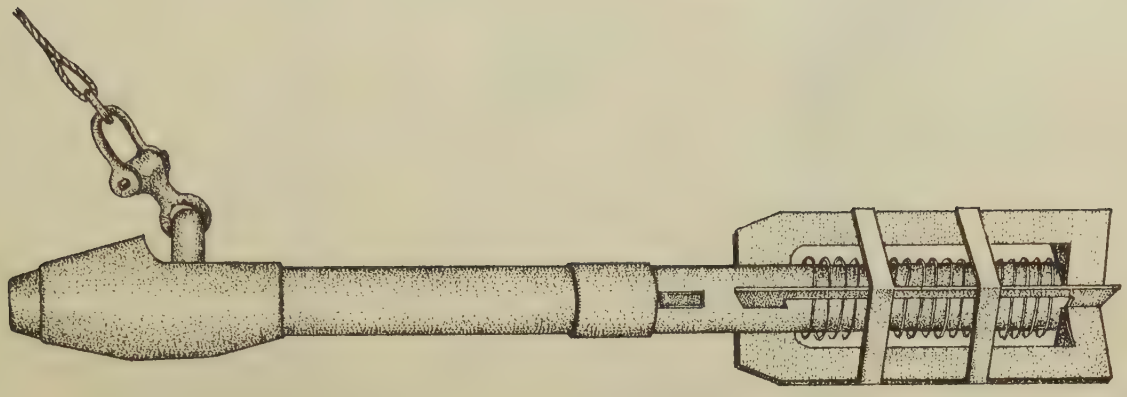
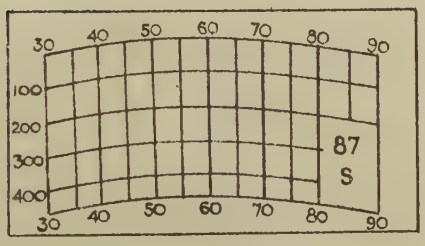


Fig. 7.2 Reversing thermometer (pressure protected) and construction of the capillary





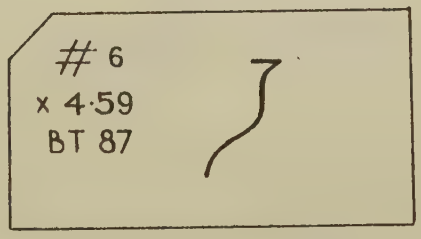


Fig. 7.3 Bathythermograph, grid for reading recording and typical recording

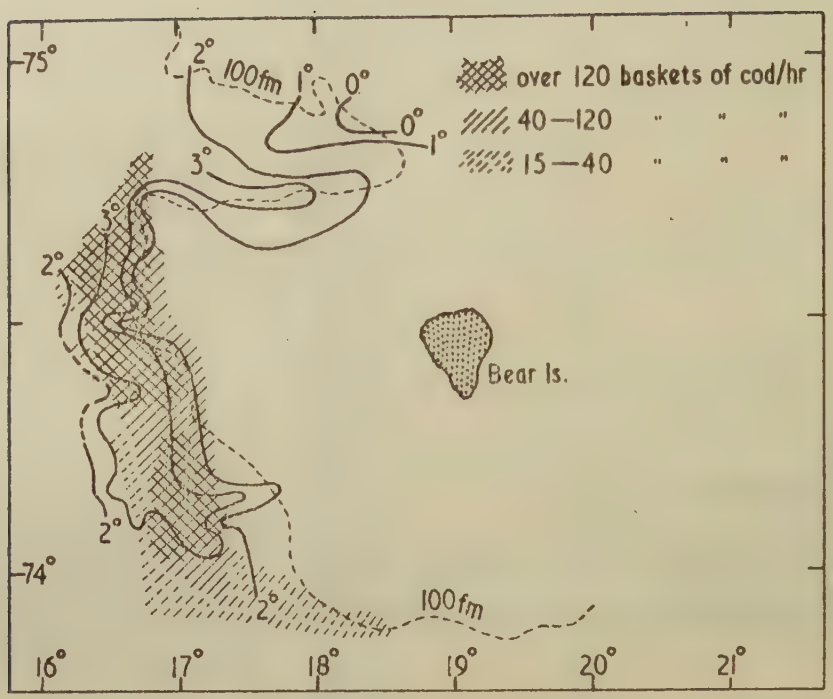


Fig. 7.4 Distribution of cod and bottom temperature in Bear Island area in early summer

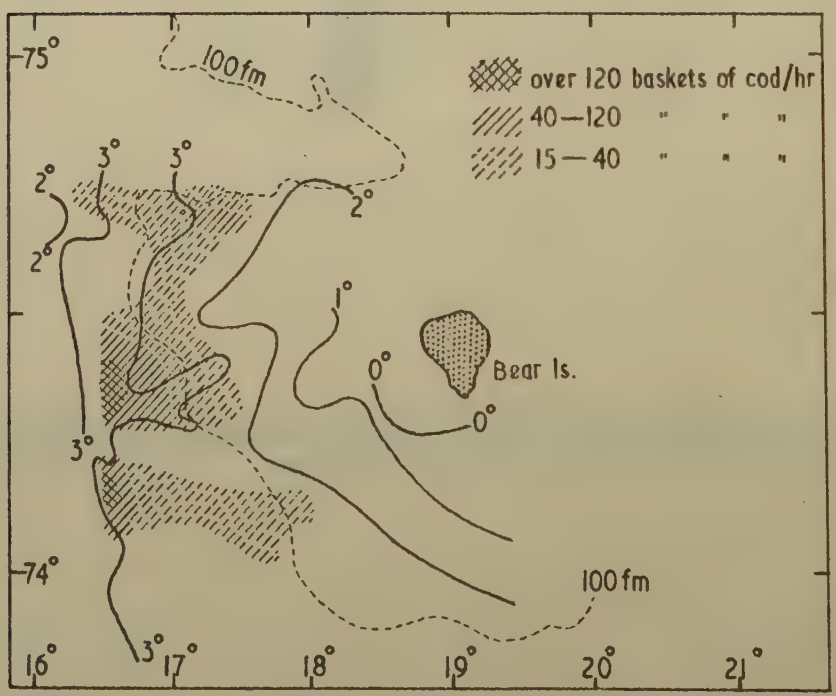


Fig. 7.5 Distribution of cod and bottom tempoerature in Bear Island area later in summer when warm water has spread eastward

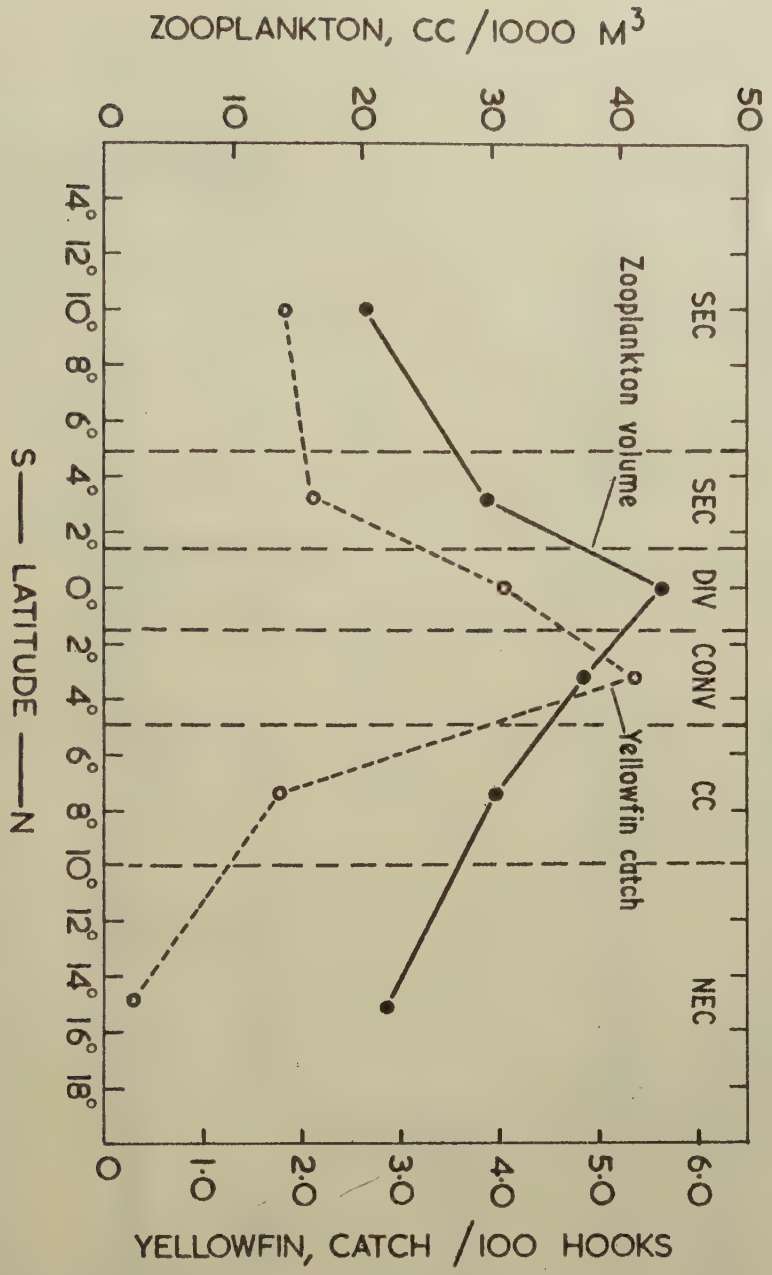


Fig. 7.6 Variations with the current system in yellow-fin catch and zooplankton volume

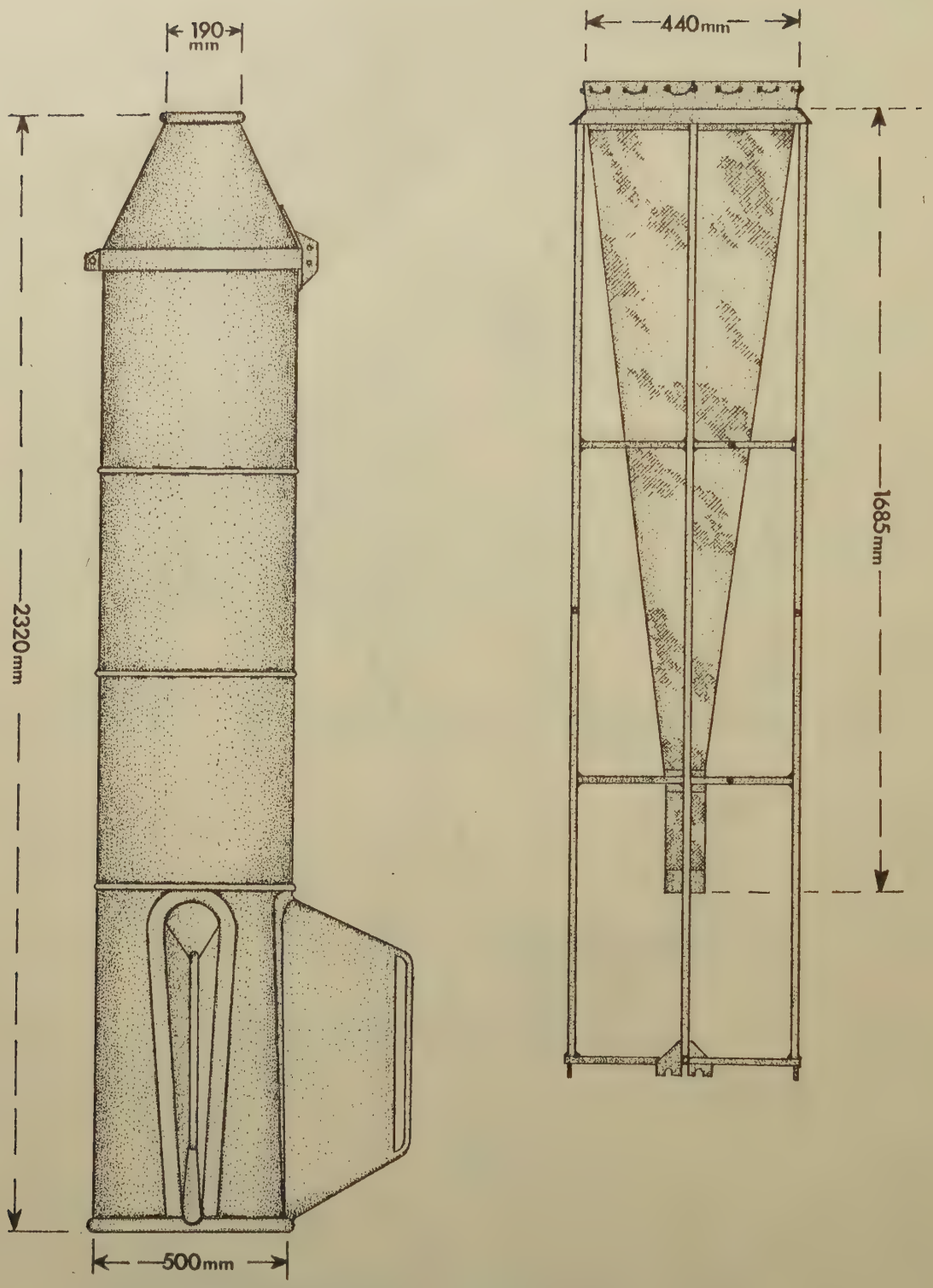


Fig. 7.7 Dutch modification of Gulf III sampler

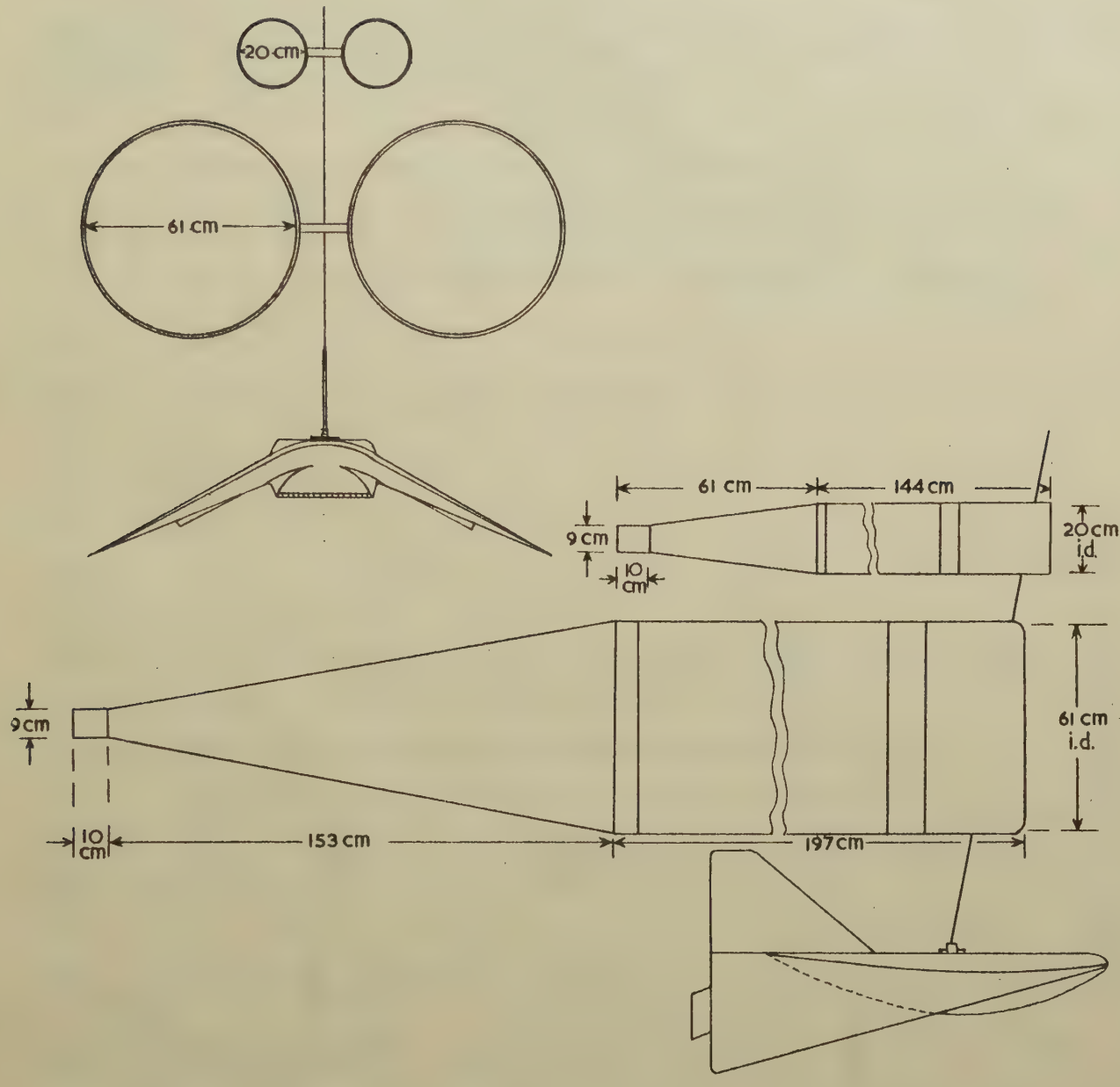


Fig. 7.8 Side view of Bongo samplers

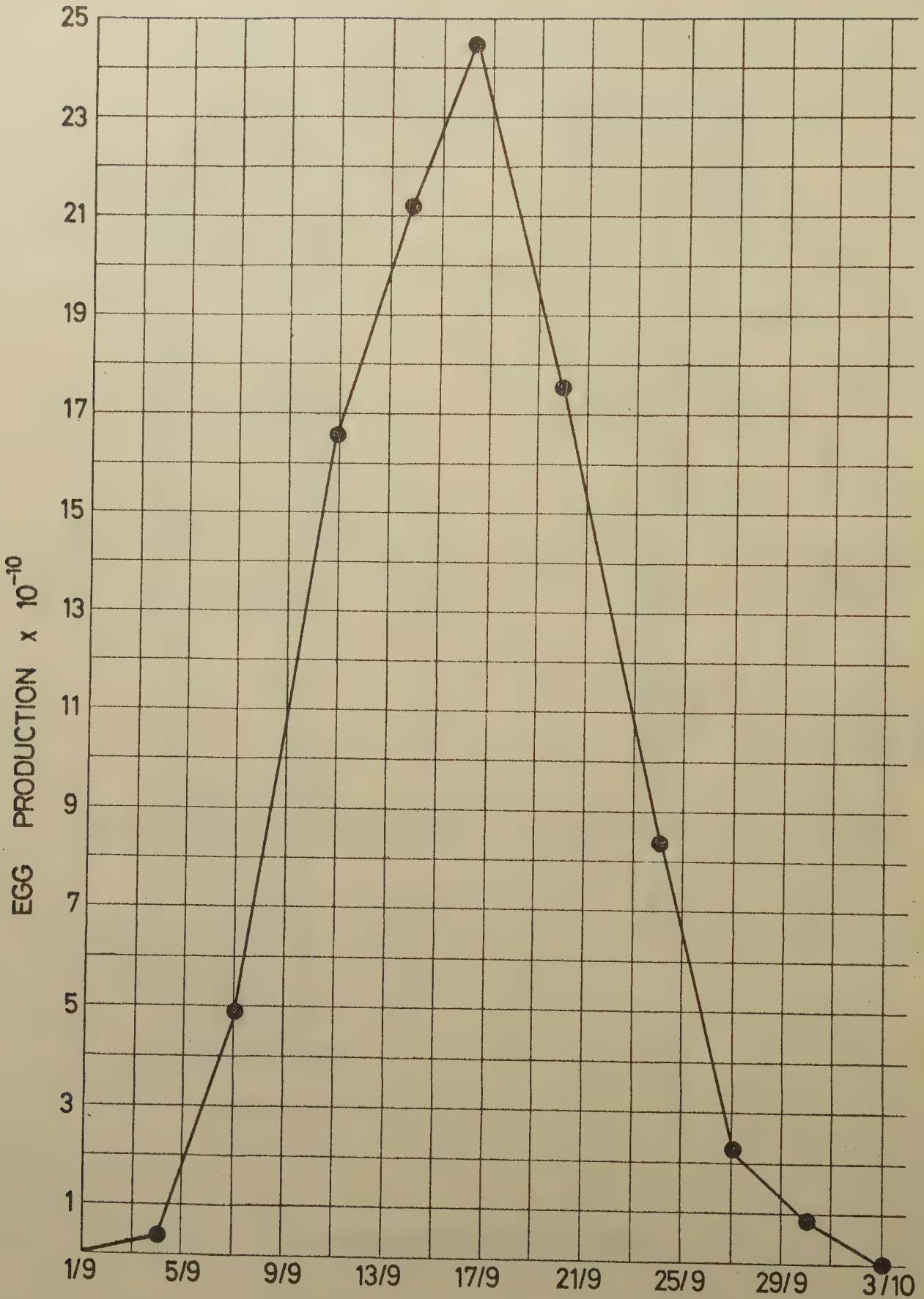


Fig. 7.9 Plot of daily egg production against time for haddock egg survey.

APPENDIX 7.1

Worked example of correction of temperature readings

This example is taken from Hydrographic Department Professional Paper No.19, "Temperature and Salinity Measurements using reversing water bottles", published by the Hydrographic Department, Ministry of Defence (Navy), London, 1967. This publication gives an excellent step-by-step account of how to take such measurements.

T^1 = temperature read from the protected reversing thermometer = 3.40°C

t = temperature read from the auxiliary thermometer = 19.5°C

V_o = degree volume of protected reversing thermometer = 67°C

K = thermal coefficient of protected reversing thermometer = 6100

I = index of correction of protected reversing thermometer = -0.07°C

$$\Delta T = \frac{(T^1 + V_o)(T^1 - t)}{K - 100} + I$$

$$\Delta T = \left[\frac{(3.40 + 67)(3.40 - 19.5)}{6100 - 100} + (-0.07)\right]°C$$

$$\Delta T = \left[\frac{(70.40)(-16.10)}{6000} - 0.07\right]°C = -0.26°C$$

$$T_w = T + T^1 = \left[-0.26 + 3.40\right]°C = 3.14°C$$

That is, actual temperature at reversal (T_w) = 3.14°C

T_u^1 = temperature read from the unprotected reversing thermometer = 13.50°C

t_u = temperature read from auxiliary thermometer = 19.7°C

V_o = degree volume of unprotected reversing thermometer = 159°C

K = thermal coefficient of unprotected reversing thermometer = 6300

I = index of correction of unprotected reversing thermometer = -0.15°C

$$\Delta T_u = \frac{(T_u^1 + V_o)(T_w - t_u)}{K} + I$$

$$\Delta T_u = \left[\frac{(13.50 + 159)(3.14 - 19.7)}{6300} + (-0.15)\right]°C$$

$$\Delta T_u = \left[\frac{(172.5)(-16.56)}{6300} - 0.15\right]°C$$

$$\Delta T_u = \left[-0.47 - 0.15\right]°C = -0.62°C$$

$$T_u = T_u^1 + \Delta T_u = 13.50 - 0.62 = 12.88°C$$

That is, true temperature at reversal plus the effect of temperature is 12.88°C (= T_u)

To calculate the depth:

d = mean density of sea water at reversal depth = 1.029

$\mathfrak{q}$ = pressure coefficient of the unprotected reversing thermometer = 0.00954

$$= \frac{T_u - T_w}{\mathfrak{q}d}$$

$$= \left[\frac{12.88 - 3.14}{1.029 \times 0.00954}\right] m = \left[\frac{9.74}{1.029 \times 0.00954}\right] m$$

= 993 metres

The actual depth at which reversal occurred was 993 metres compared with 1000 metres recorded on the meter wheel slowing wire out.

8. UNIT STOCKS, MIGRATIONS AND STOCK DIFFERENTIATION

8.1 The Unit Stock

The unit stock is a concept of fisheries biology that has its practical application in the treatment of data from fisheries. In stock assessment work we must know which data may be grouped together because they refer to individuals with a similar life pattern. To enable us to do this we describe each fish as belonging to its own unit stock.

A unit stock can be theoretically described as a group of individuals of the same species whose gains by immigration and whose losses by emigration, if any, are negligible in relation to the rates of growth and mortality. A unit stock is essentially a self-contained population with its own spawning area. It is isolated and fishing upon one unit stock has no effect upon the individuals of other stocks.

One unit stock which conforms almost completely with this definition is that of the Arcto-Norwegian cod. This spawns inside the Lofoten Islands, northern Norway; the eggs and fry are carried in the North Atlantic drift to Spitzbergen and into the Barents Sea, both of the areas forming the nursery grounds. Eventually the cod mature at 7 years and older when they return to the Lofoten Islands to spawn. There is very little emigration from the stock and no evidence whatsoever of immigration.

The cod stock at Iceland is similar except that probably some of the eggs spawned at Iceland drift to the extreme south-west corner of Greenland and, in some years, there is a return migration of mature cod to spawn at Iceland. Both the Icelandic and southern Greenland cod stocks are treated as separate stocks for assessment purposes, but the theoretical concept of complete isolation is no longer true.

The concept is further blurred in the case of the North Sea herring, of which there are three distinct populations, Downs, Dogger and Buchan. They have separate spawning grounds but intermingle on the feeding grounds at certain times of the year. These three herring stocks cannot be treated as unit stocks because the fishing mortality is common during that part of the year when they are mixed but, insofar as possible, data for three populations are collected separately and the populations assessed separately.

The North Sea cod presents the furthest departure from the concept of a unit stock. It is distributed all over the North Sea, but tagging experiments have indicated that the mixing of juvenile and adult fish from different spawning grounds is a very slow process, which can be illustrated by a series of overlapping circles. Fig. 8.1.

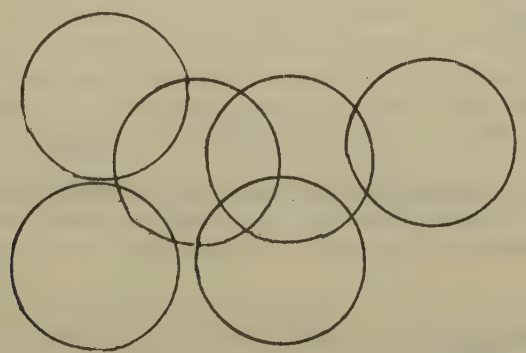


Fig. 8.1 Overlapping circles representing North Sea cod populations, each based on a spawning area

Cod from one spawning area mix with those spawned in an adjacent area and the one next to that, but individuals at the opposite ends of the areas will probably never mix. Consequently, exploitation of the cod in one part of the North Sea will not affect the whole population in the same way.

Neither the individual populations derived from a single spawning nor the whole set of populations can be considered as falling within the definition of a unit stock, although it is practical to assess the North Sea cod as two unit stocks.

All these examples are taken from the North Atlantic but similar variations in the degree of separateness exist elsewhere. In Lake Mobutu Sesseseku (Albert) at least two populations of Alestes baremose exist, one at the north and one at the south end of the lake, based upon spawning grounds in the rivers Nile and Semliki respectively. Distance prevents fish of the two populations mixing and they form two unit stocks, even though they are biologically and probably genetically inseparable. Non-migratory fish in rivers probably form a similar parallel to cod in the North Sea.

Thus, although the term 'unit stock' has a strict definition its practical application depends upon the extent to which individuals of a stock can be identified. With increasing knowledge of a 'unit stock' it may be possible to divide it into two or more 'unit stocks', as is happening with North Sea cod. Originally assessed as a separate stock it is now being assessed on the basis of a northern and a southern stock.

8.2 Migration

Individual members of the unit stock are rarely sedentary and a knowledge of the migration of fish species is most important and useful when dealing with their biology and dynamics since the distribution of the effort of the commercial fishery may be closely related to the pattern of migration of the species concerned.

Nikolsky (1963) defines migration of fishes as an active, but occasionally passive, main movement from one habitat to another, and Heape (1931) as a class of movements which impels migrants to return to the region from which they have migrated. Jones (1968) remarks that the word 'impels' is used in the sense of biological necessity.

Both Heape (1973) and Nikolsky (1963) note three main movements in the migratory cycle of fishes:

1. Spawning migration
2. Feeding migration
3. Wintering migration

Nikolsky (1963) mentions that the reason why some fish species migrate is that there is not enough food for both the adult and the young parts of a large population to live in the same area. They have to either increase their feeding areas or restrict their abundance.

Jones (1968) discusses Nikolsky's work and theories and mentions that if migration is an adaptation to abundance it would explain why the important commercial species are migratory; they are of commercial interest because they are abundant and abundant because they are migratory.

8.2.1 Migration and currents

The current can be considered as the mechanism into which the unit stock is locked, holding its members together to form that unit stock, and patterns of migration are described in terms of these currents. Pelagic eggs and larvae drift with the current (a denatant movement) to the nursery area (a feeding migration) and the adult individuals swim

against the current (a contranatant movement) back to the spawning area (spawning migration) as shown in Fig. 8.2.

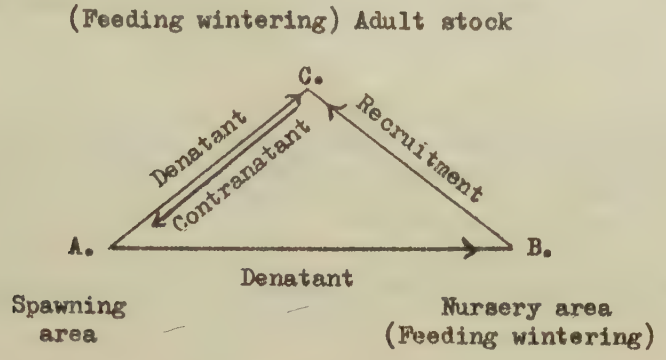


Fig. 8.2

Some marine fish, such as herring, and the majority of freshwater fishes do not have pelagic eggs but fix them to plants or the substratum. Some species notably the cichlids are mouth brooders. This is not only an adaptation which provides the eggs and fry with parental protection but also enables the species which occur in rivers to spawn without migrating upstream as do the majority of riverine fish. During the time from spawning and until the hatched larvae are able to withstand the current the larvae may be carried very long distances away from the spawning area. Therefore, a spawning area must be in such a position in relation to the direction of the currents that the larvae and young fish are carried to nursery areas where suitable feeding conditions exist. The spawning migrations of adult fish are normally an active migration against the current (contranatant) to compensate for this.

If the main currents in the sea are principally responsible for the migrations of fish it could help to explain the absence in the tropical zone of species which perform regular long-distance migrations. Cushing (1959) mentions that in the tropical zone the environmental conditions can always be favourable for the development and survival of eggs and larvae at all times of the year and in all localities covered by an inter-tropical gyral.

In the temperate or arctic zones, where food is not available in more or less equal quantities throughout the year, production cycles differ from those in the tropics. Thus, if the young are to survive in these zones the adult fish have to spawn in the right place and at the right time. It follows from this that in the temperate and arctic zones there must be an annual cycle of activity in the gonads.

8.2.2 Terminology of fish migration

The following terms and definitions of fish migrations proposed by Meyer (1949) have been generally adopted:

(a) Diadromous

Truly migratory fishes which migrate between the sea and freshwater.

(b) Anadromous

Diadromous fishes which spend most of their lives in the sea and migrate to freshwater to breed (salmon, sea trout, shad, sea lampreys, sturgeons).

(c) Catadromous

Diadromous fishes which spend most of their lives in freshwater and migrate to the sea to breed (eel, Salangidae, Galaxidae, Retropinnidae).

(d) Amphidromous

Diadromous fishes which migrate from the sea to freshwater or vice versa, but not for the purpose of breeding (some Exocidae, Perca fluviatilis, some Mugilidae).

(e) Potamodromous

Truly migratory fishes the migrations of which occur wholly within freshwater (trout, bream, Coregonoids).

(f) Oceanodromous

Truly migratory fishes which live and migrate wholly in the sea (cod, herring, capelin, tuna, mackerel).

8.3 Methods of Studying Fish Migrations

This should, in fact, be termed 'methods of tracing fish migrations' because attempts to explain them in real terms are rather more difficult. There are numerous methods for tracing the migrations of fishes.

8.3.1 Marking

It is not possible to fit successfully tags to all fish species and all size groups of fish. In such cases the fish may be marked by fin clipping. Fig. 8.3 shows some combinations of fin clipping which have been used. If possible some fish should be kept in captivity to determine how long it takes the fish to re-generate. This can be a matter of weeks in tropical conditions. Adipose fins do not regenerate. Similar problems are experienced with crustaceans like lobsters, because these animals cast their shells during moulting. Clipping of the telson as shown in Fig. 8.4 should be satisfactory and still visible at least after two moultings.

Small fish can also be marked by injecting liquid latex and colour coding allows a limited amount of differentiation between groups of marked individuals (Riley, 1966). These methods are only satisfactory if the total number of lobsters or fish landed is relatively small and they can be handled and examined individually.

8.3.2 Tagging

A large number of different devices have been used for tagging fish and shellfish. In the Journal du Conseil (ICES, 1965) about one hundred tags are figured and briefly described. Numerous papers have been written on the subject, which it is impossible to cover in detail here. Only the main types of tag and tagging methods will be described.

8.3.2.1 General characteristics of a tag

Any fish tag should be as small as possible so as to cause least interference with the normal behaviour of the fish. External tags should not be so conspicuous that they make the fish more vulnerable to predation but must be easily visible to the potential finder, two conflicting requirements which are usually solved in favour of the latter. They must be

cheap and easy to make because many thousands are usually required and, if possible, they should be entirely machine made to minimize demands on manpower. Each should have a number which uniquely identifies the fish to which it is attached.

8.3.2.2 Internal tags

Internal tags are used on fish, such as herring, anchovy and whiting which are landed in large quantities for reduction to meal and oil. They are not handled individually and the chance of an external tag being noticed are very small. Internal tags are small steel plates with identifying letters and numbers (Fig. 8.5). They are put, or shot, into the body cavity with a pair of pincers or a gun (Fridriksson and Ansen, 1962; Ansen et al., 1961). In order to remove pieces of iron, which may have been accidentally dropped amongst the fish, strong magnetic separators are fitted to the conveyor belts carrying the fish into the factory. The steel tags also collect on these. During the period August 1969-March 1970, 58,000 young herring were tagged in this way in the North Sea.

Internal tags are also used on prawns and shrimps which are also landed in large numbers but which are individually handled in processing. These tags are plastic and are inserted laterally into the musculature of the first abdominal segment (Fig. 8.6).

8.3.2.3 External tags

The majority of tags in use are external tags of which only a limited number will be described:

1. The Petersen disc (Fig. 8.7)

The Petersen disc has been one of the most successfully and widely used tags in the history of fisheries biology. It consists of two plastic buttons which are attached one on each side of the fish with a pin made from either titanium or stainless steel wire; silver wire used to be used but it becomes brittle after one year and tag shedding results. The method of making the wires and attaching the tag are shown in Fig. 8.7. As the wire is bought in reels the pins have to be cut; if alternate cuts with wire cutters are made at 45° a point is formed on two consecutive pins with one cut. These points are very sharp and care should be taken in handling pins.

One of the discs carries an identification number and letter or letters. Within ICES member nations the latter are internationally-agreed so that details of recaptured fish can be returned to the country of origin irrespective of where they are caught.

On flatfish, such as plaice, the tag is fitted just below the dorsal fin (Fig. 8.7); on rays it is fitted on one of the pectoral fins midway between the gill slits and the apex of the fin. On roundfish it is also fitted below the dorsal fin. It should not be fitted to bony structure such as the operculum because the wire erodes the bone and the tag is quickly lost. When the fish is tagged the discs should be loose on the wire, with up to 5 mm slack depending upon the size of the fish, to allow for growth.

2. The Lea tag (Fig. 8.8)

The Lea tag is a cylinder of plastic containing a message, number and letter code printed on paper. Usually the cylinder is yellow in the central part and blue at the ends. This tag is termed 'hydrostatic' because it is neutrally buoyant in water. It is used exclusively on round fish and is normally fitted to the fish in front of the (first) dorsal fin, preferably with a soft-braided nylon;bridle; those of wire or monofilament nylon cut the fish flesh, causing wounds and eventually shedding of the tag. The bridle is sewn through the fish using a curved surgical needle with a split eye into and out of which the bridle can be easily slipped (Fig. 8.9). This tag has been used mainly on herring,mackerel and cod.

3. The plastic flag tag (Fig. 8.9)

Because the Lea tag has to be assembled by hand, it has largely been replaced by the flag tag, made from sheet polythene. These are stamped indelibly with a message and the number written on with special insoluble ink. The size of the flag can be designed to suit the size of fish being tagged. Until recently it was possible to obtain these flags with a mercury salt incorporated in the plastic which eliminated fouling. However, restrictions on the use of mercury and difficulties in printing on the impregnated plastic have resulted in supplies of this type being discontinued. The flag tag is attached with a soft braided nylon bridle, as the Lea tag. (Fig. 8.9).

4. The spaghetti tag

The spaghetti tag (Fig. 8) is a length of yellow polythene plastic tubing, 20–30 cm long with an external diameter of 0.10–0.35 cm. Instructions to the finder are either printed directly on the tube or on a red plastic label fitted inside it. The tube is sewn through the back of the fish using a curved surgical needle, whose blunt end is designed to fit into the tube leaving its outside flush with that of the needle (Fig. 8.11). The spaghetti tag has the advantage that it does not need a separate bridle. Their disadvantage is that it is difficult to get the needles to match the tags, which often slip off during insertion.

Recently manufactured plastic flags which have no bridle and which can be inserted with a gun have become available (Rauck, 1969). This method of application is very quick and the results obtained appear to be as satisfactory as obtained using older methods.

5. Plate tags

In Scotland, for salmon smolts, a pair of small plastic or stainless steel plates 30 mm by 6 mm is used. These plates are fastened one each side of the base of the dorsal fin with wire, which passes through holes at each end of the plates. The tags are meant for recovery when the fish has returned to freshwater after life in the sea. During this period the flesh covers the tag so to identify the tagged fish, most of which are individually handled, the adipose fin is removed at the same time as the smolts are tagged.

6. Tags used on molluscs

Molluscs have been tagged in two ways. One method is to slightly grind the shell to give a dry, smooth surface and then attach a numbered Petersen with waterproof glue (Thomson, 1963). The other method, suitable for scallops, is to drill a hole through the anterior ear of the flat valve with a power drill and attach a numbered Petersen disc with stainless steel wire (Rolfe and Franklin, 1973).

7. Tags used on crustaceans

Crustacea have been tagged by wiring Petersen discs to their shells (Simpson, 1963) but these are lost at moulting. The suture tag has been used to overcome this problem with crabs; a piece of surgical wire is sewn through the epimeral line of the crab and onto this a numbered Petersen disc is threaded, the ends of the thread being sealed together with a lead seal (Mistakidis, 1959) (Fig. 8.12). Various methods have been used to tag decapod crustacea including small Petersen discs and dart and loop tags inserted at the junction of the cephalothorax and abdomen (Fig. 8.13). Neal (1969) reviews methods of making and tagging shrimps.

8.3.3 Tagging experiments

8.3.3.1 Planning the experiment

When planning a tagging experiment it is necessary to:

(a) select a tag which is suited for both the species and the commercial fishery concerned; for example, Petersen discs used on fish which are most likely to be caught in a gill net or stake net will make the fish more vulnerable to capture than untagged fish because the meshes will catch on the wire between the fish and the discs;

(b) choose a fishing gear which will not damage the fish when catching them;

(c) choose the right season of the year;

(d) choose the right depth for catching, if there is a choice; if the fish are in water deeper than about 40 m those species with closed swimbladders, like cod, haddock and hake, will often come up completely bloated because the process of reabsorbing the gas from the swimbladder is slow and the overpressure (1 atmosphere for every 10 m of water) leads to the swimbladder expanding;

(e) issue publicity to the fishermen about the tagging experiment;

(f) place all the tags, in order, in a secure fashion (on a piece of wire) so that they cannot be lost and have all other equipment carefully labelled and easy to hand;

(g) secure suitable facilities on board the ship: tank capacity, running water and measuring boards.

It is also necessary to have sufficient tags to tag that number of fish which will give a meaningful result. This means knowing something about the likely return rate. If possible a pilot scheme should be run first but this is not always possible.

8.3.3.2 Running the experiment

To keep the fish in the best possible condition:

(a) use the gear which will cause them the least damage; purse-seines are best for pelagic fish if it is possible to catch them that way; bottom trawls should be rigged to catch the least possible amount of benthos and stones and the codend should be of soft material; Maucorps and Lefranc (1973) describe a canvas codend which minimizes water movement within it during towing and retains water on hauling.

(b) transfer the fish from the gear to the holding tanks as gently and as quicky as possible; these tanks should have a continuous supply of running water if possible; if not, the water should be renewed as often as possible with a bucket so as to keep it well oxygenated and its temperature near ambient;

(c) remove fish which are dead, swimming belly up or have visible damage;

(d) measure the fish and if possible record both the sex and the maturity. Record these details and any others needed against the number of the tag in a logbook;

(e) fit the tag to the fish as quickly as possible;

(f) liberate the fish and record the position of liberation. Normally this is recorded for each block of tagged fish released at that station. Fish with expanded swimbladders can be successfully released by putting them in a cage which can be opened at depth from the ship. The fish in the cage are lowered as deep as possible, the door of the cage opened and the cage retrieved.

8.3.3.3 Rate of returns from a tagging experiment

The rate of returns from a tagging experiment is affected by:

(a) the fishing mortality rate;
(b) the natural mortality rate;
(c) death of fish caused by capture and tagging
(d) loss of tags.

The fishing and natural mortality rates are two parameters which can be measured from a well-conducted tagging experiment but the accuracy of their estimation will depend upon death of fish caused by tagging and loss of tags.

Death of fish due to capture and tagging can rarely be eliminated entirely. The stress of capture, which results in lactic acid accumulating in the blood, can be lethal and Bagge (1970) found that this factor was more important than any other. Strict regard to factors (a) - (b) described in section 8.3.3.2 will minimize death from this cause.

It is possible to get an estimate of this mortality by:

i) keeping the tagged fish in tanks or keepnets for some hours;
ii) using two different types of tags;
iii) classifying the individuals tagged according to behaviour in the tank before tagging and to visible damage (loss of scales, etc.).

Beverton and Bedford (1963) classified whiting which they were tagging by scale condition (good, moderate and poor) and by the way of swimming (floaters, swimming belly up in the tank, and sinkers, swimming lively around the bottom of the tank). The fish classified as "good - sinkers" yielded returns four to five times higher than "poor - floaters" and "poor - sinkers" respectively.

Death of fish can also be caused if the tag is either unsuitable and leads to rejection, or makes the fish more liable to predation or leads to the fish becoming entangled in plants or upon rough rocks.

Loss of tags is caused by either the fish shedding the tag or the tag not being returned after the fish carrying it has been recaptured. Loss of tags can be avoided by choosing a suitable form of attachment (titanium or stainless steel but not silver pins for Petersen discs, suture and not-wired-on tags for crabs, both mentioned previously). Losses can be checked by running a double tagging experiment either with two tags attached by different methods to the same fish or by tagging alternate fish with different tags. Fish can also be kept in aquaria to determine loss rates.

Loss of tags after the fish has been captured can be caused in many ways. The tag may not be easy to detect or it may carry insufficient instruction to the finder as to what he should do with it. The finder should get a reward which is large enough for him to make it worthwhile returning the tag and its level should be reviewed at annual intervals to make sure its relative value does not fall as other prices increase. If the fishis returned the value of the fish should be paid plus any other expenses.

In some countries premium awards are made. Not only does the finder get a reward but all the numbers of the tags returned over a given period are put into a lottery and the winner gets a very large prize with attendant publicity. This is better than having one tag for which there is a big prize because once it is known that this fish has been caught interest in looking for tags rapidly drops. These methods can be used only where gambling does not offend the fishermen's moral code.

The finder should be given information as to where the fish was tagged and what is the purpose of the experiment. International arrangements need to be made so that tags used by one country and returned to that of another are accepted, paid for and the information passed on. Tags may not be handed in for peculiar reasons; if the fishermen do not get on well with the fisheries biologist they will enjoy not returning his tags; sometimes fishermen will not return the tags of one nation whom they dislike for some reason; care must also be taken that the tags used do not have any symbolic or religious significance that might anger the fishermen.

Methods used in analyzing tagging experiments are given by Jones (1966).

8.4 Other Methods of Differentiation Between Stocks and Following Migrations

8.4.1 The distribution of fishing effort

By studying the distribution of the fishery on a species it is possible to gain some idea of changes in availability in different areas which may indicate migrations of the recruited stock. These data are particularly useful at spawning time when the mature part of a unit stock is likely to be separated from the mature part of any other unit stock.

8.4.2 Echo surveys

By using echo-sounders it is possible to register fish schools whose species composition may be identified by repeated fishing. Repeated surveys may indicate the directions of movements of the fish concerned. More advanced echo-sounders (integrators) make it possible, by measuring the strength of individual signals, to estimate the size of the single fish and, in several cases, the species. The movements of the Atlanto-Scandinavian herring were traced in this way.

8.4.3 Parasite studies

Studies of parasites as biological tags have given some promising results. Two parasites of the Pacific sockeye salmon, which inject it in freshwater, have been very useful in distinguishing the geographical origin of fish caught on the high seas; one is larval Triaenonphorus crassus, a cestode which occurs in the muscle and which predominates in fish of Alaskan Bristol Bay origin; the other is a nematode, Dacunitus truttae which is found in the muscle and occurs most commonly in sockeye of Asian origin. Scientists estimated the proportion of cod of Greenland origin in the spawning fishery at Iceland from the occurrence of larval codworm, Terranova decipiens which occurs only in cod of the Icelandic stock.

8.4.4 Immunogenetic techniques

The protein fractions of animal tissue can be separated by passing a low voltage DC current through them. If this is done on a slide coated with a suitable agar gel the constituent amino acids travel through the gel at different speeds to form bands. The position of the bands has to be identified by staining (Fig. 8.14).

For fish most of this work has been based on the use of blood proteins such as gamma globulin. To date the technique has been used on post-larval fish and has shown differences only between widely separated unit stocks. However, the occurrence of the different protein fractions is determined genetically and the method is now being developed to enable the work to be extended to larvae. This offers the possibility of being able to follow larvae from a particular spawning ground into their nursery areas and to link spawning stock with recruits in a more direct manner than has hitherto been possible.

8.4.5 Scale studies

From the scales of diadromous fish like salmon and sea trout, which spawn in freshwater, it is possible to gain information on the main movements between freshwater and the sea. Salmon and sea trout stay in freshwater from 1 to 7 years after hatching. During that time their growth is slow and the rings laid down on their scales are close together. When the fish migrate to the sea, their growth increases enormously and the distance between the rings becomes broad. The two types of growth pattern are easy to distinguish. After staying 1 to 3 years in the sea the fish return to freshwater to spawn. The fish then stop eating and use their fat reserves to satisfy their energy demands when swimming up river against the current. This results in a spawning mark on the scales in the form of a ring somewhat different from the annual rings. If the salmon survive the spawning they return to the sea and start eating again and the distance between rings is again large. The number of years which juvenile salmon stay in freshwater varies between countries so the number of juvenile rings also indicates the country of origin. (See also section 4.1.8.3).

8.4.6 Meristic character

Meristic characteristics are those which are countable such as vertebrae, fin rays, scales and fecundity. Several authors have shown that there is a relationship between some meristic characters and the environmental conditions to which the eggs and larvae are exposed.

Schmidt (1921) showed that eggs of trout from the same parents, incubated at various temperatures, produced fry in which the average numbers of vertebrae were higher at both low and high temperatures (3° and 9°C). Tåning (1944) confirmed Schmidt's results and also showed that the number of rays in the pectoral and the dorsal fins increased with temperature. Zijlstra (1958) combined all data on herring given so far on vertebra counts and the temperature on the spawning grounds, and demonstrated a clear negative correlation (Fig. 8.15).

The same result has been demonstrated experimentally by Hempel and Blaxter (1961) who also showed a generally positive correlation between salinity and myotome counts (Fig. 8.16).

Hempel and Blaxter (1967) also showed a relation between the individual egg weights of North East Atlantic herring and the spawning time (Fig. 8.17) which they explained as an ecological adaptation to environmental conditions. Evidence is also accumulating that meristic characters are also partly genetically determined. Thus, fish of similar genetical pattern (of the same stock) are likely always to spawn in the same area. The conditions in this area at spawning time are likely to be uniform from year to year because the eggs and larvae are less tolerant of a wide range of environmental conditions than the adults and therefore the adults must be adapted to return to the area where these conditions exist. In consequence the meristic characteristics will not change from year to year and they become diagnostic of the stock.

Individuals cannot be separated by their meristic characters but only populations by their differences in mean numbers. Also, it is usual to use two or more characteristics and to combine the data by means of mathematical techniques such as discriminatory functions and distance functions (Fischer, 1936 and Rao, 1962).

The meristic characters which have been or are currently in use for stock identification are as follows:

A. Morphological

i) Vertebral number
ii) Keel scale number
iii) Fin ray number
iv) Gill-raker number
v) Body proportions
vi) Individual skeletal structures.

B. Physiological

i) Spawning time and maturity stage
ii) Growth in the first year (more precisely the formation of the first winter scale ring; (see section 4.3)
iii) The overall pattern of growth.

By far the greatest attention has been paid to the morphological characters, vertebral number, keeled scale, number and body proportions and to physiological characters, spawning time, fecundity and growth.

One other characteristic that can be used for separating stocks which is not meristic is overall external appearance, such as shape and pigmentation.

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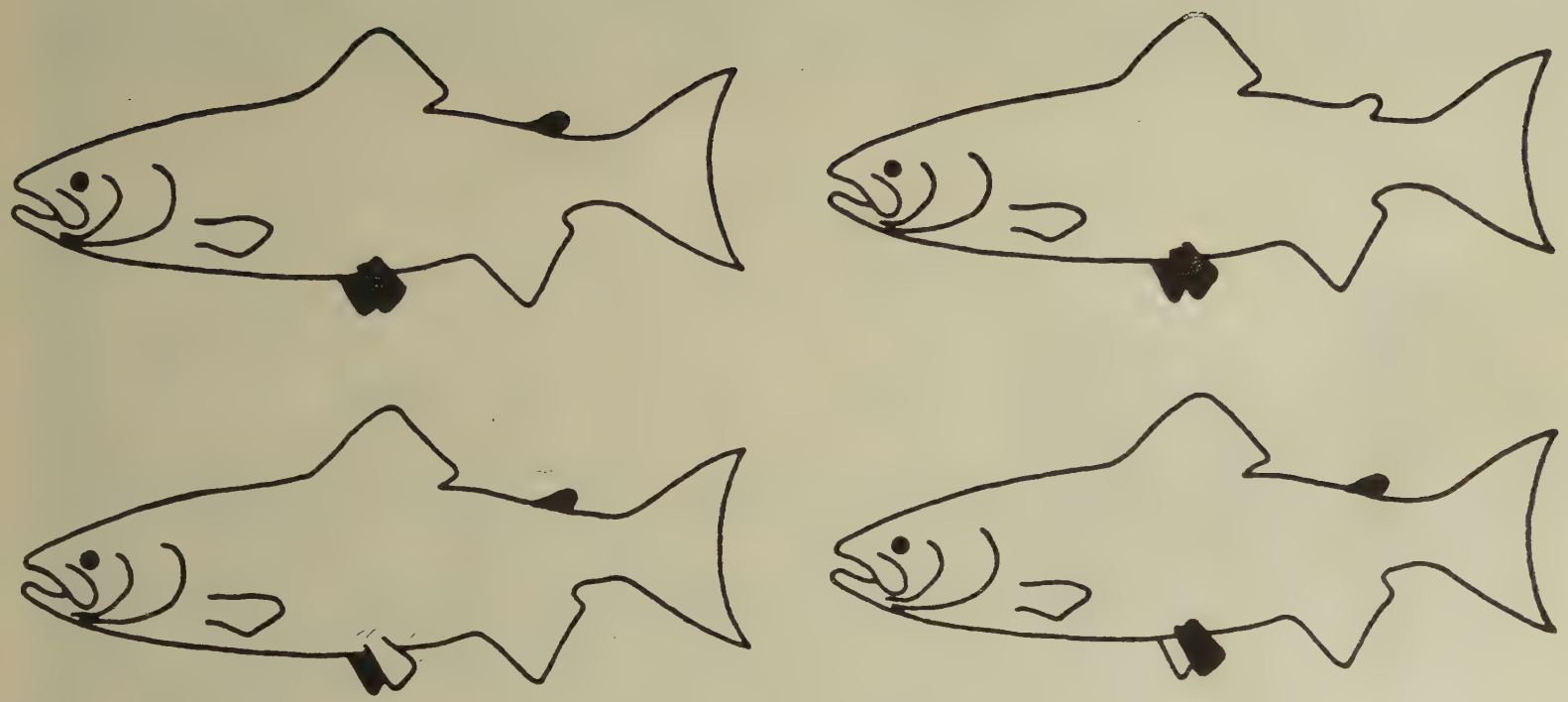


Fig. 8.3 Combinations of fin clipping used to mark salmon smolts at Cultus Lake, Fraser River, British Columbia (after Foerster, 1937)

Fig. 8.4 Telson of lobster marked by clipping (after Poulsen, 1967)

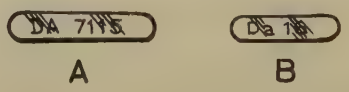
Marking Institution	Danmarks Fiskeri- og Havundersøgelser, Charlottenlund Slot, Charlottenlund.
Type	Internal tag made of stainless steel or nickel-plated iron. (A) 20 × 4 × 1 mm. Stamped DA and a number. (B) 14 × 3 × 0·4 mm. Stamped Da and a number, usually denoting a series of 50 tags.
Figure	 A B
Use	**Whiting** and **Sandeel.** Placed in the abdominal cavity of the fish.
Scale of Reward	Fish with full information ..... 10·00 D. kr.
Reception Office	Same as Marking Institution.

Fig. 8.5 (After ICES, 1965)

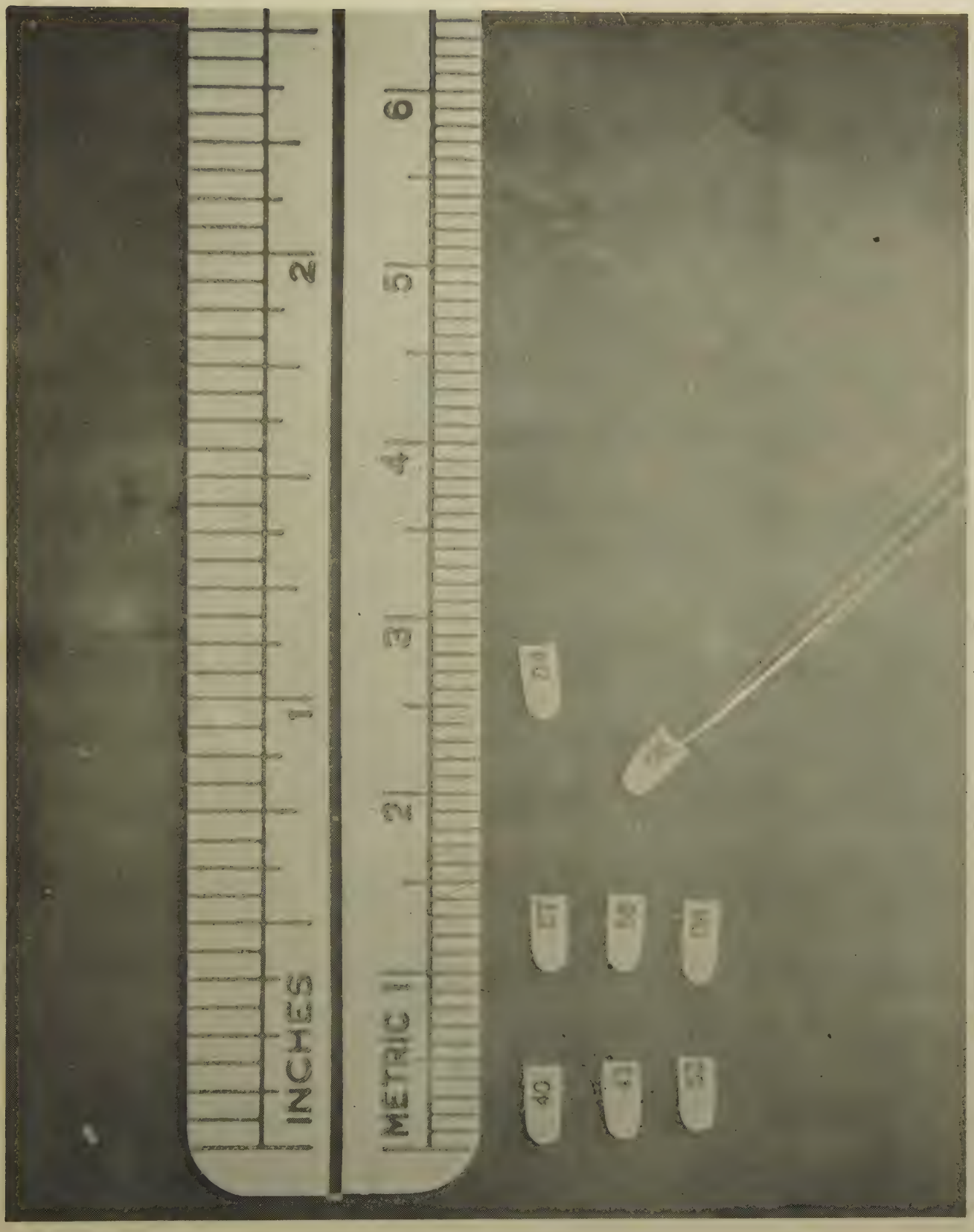


Fig. 8.6(a) ' Internal polyvinyl chloride shrimp tags. (from Neal 1969)

Fig. 8.6(b) Method of insertion of internal polyvinyl chloride tags. (from Neal 1969).

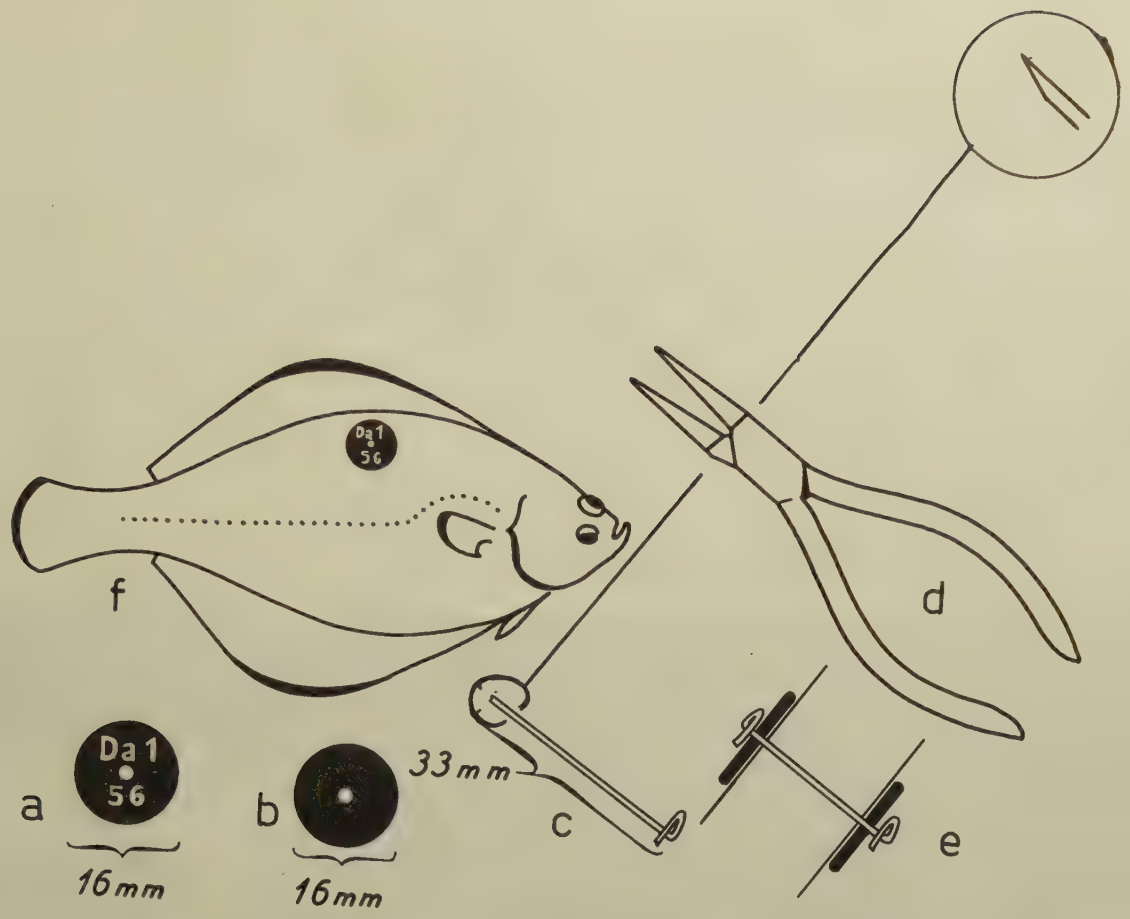


Fig. 8.7 Petersen disc (after Bagge, 1970)
Note enlargement of wire point)

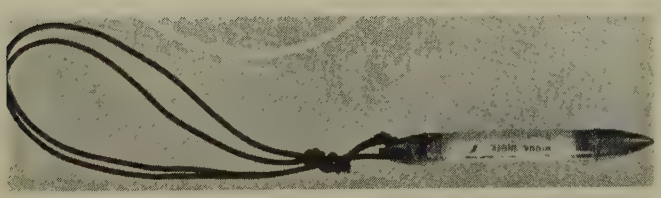


Fig. 8.8 Lea tag with braided nylon thread

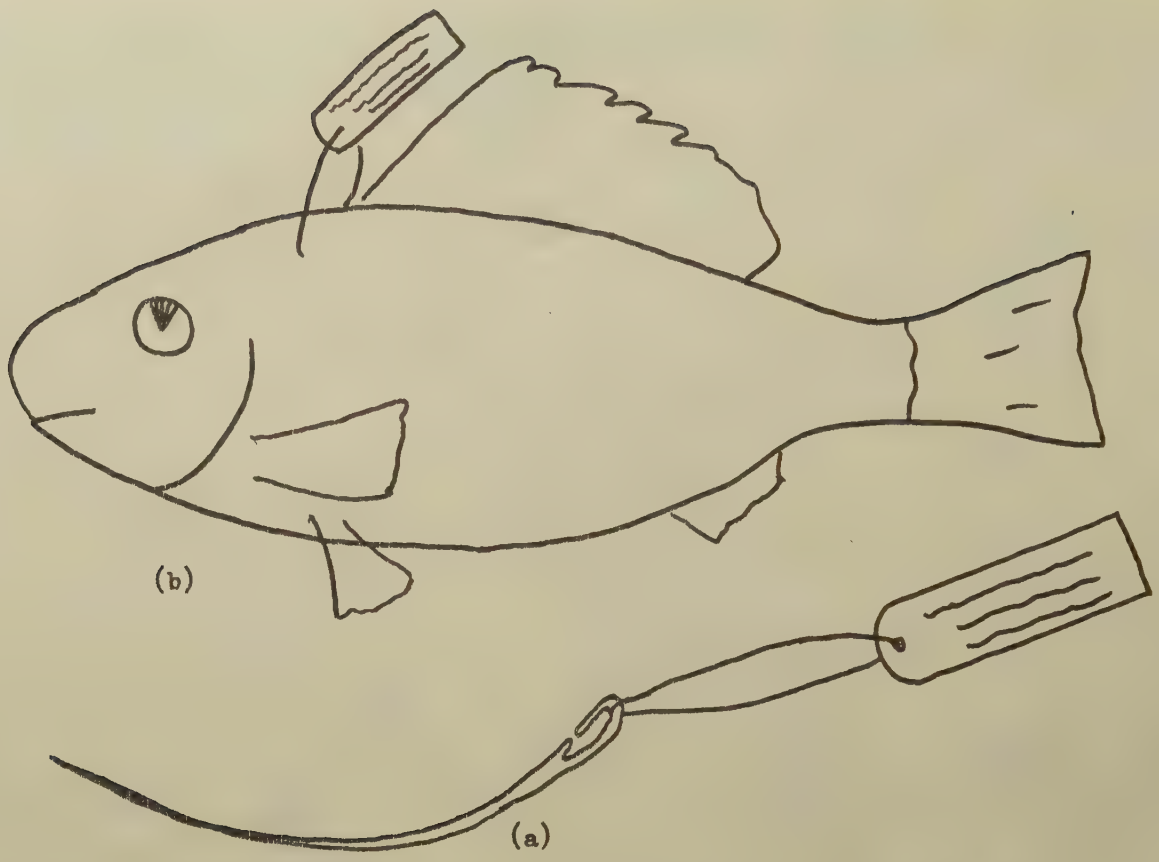
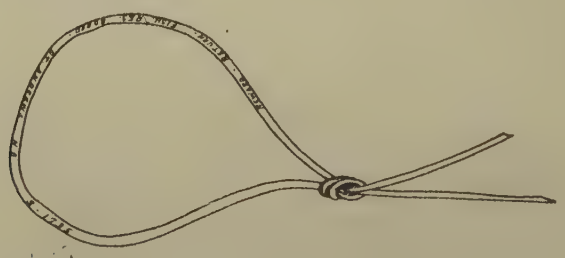


Fig. 8.9. Enlarged surgical needle showing the split eye (a) and fish tagged with a plastic flag tag (b)

Marking Institution Fisheries Research Board of Canada.

Type Spaghetti tag, yellow vinyl tubing stamped "Reward-Return Fish. Res. Board, St. Andrews, N.B., S-(number)". 30 mm × 2 mm.

Figure



Use **Cod.**
Tag attached to dorsal musculature below dorsal fin.

Scale of Reward For tag and information ..... 1·00 C. dollar.

Reception Office Fisheries Research Board of Canada, St. Andrews, N.B.

Fig. 8.10 Spaghetti tag (After ICES, 1965)

Fig. 8.11. Enlarged end of needle used to insert spaghetti tags showing butt shaped to fit inside of tube, which is shown in cross section.

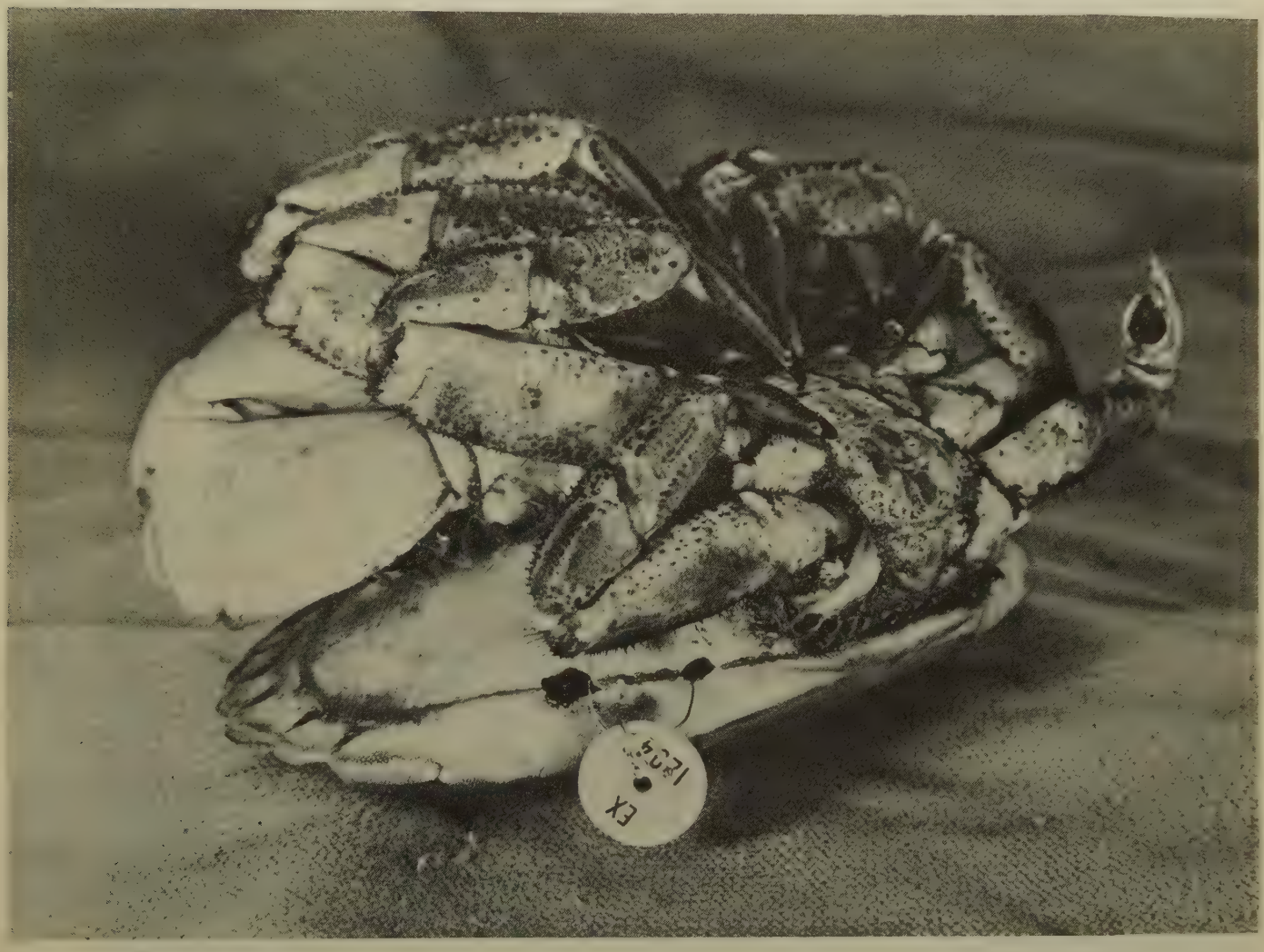


Fig. 8.12 Crab fitted with suture tag (from Mistakidis, 1959)

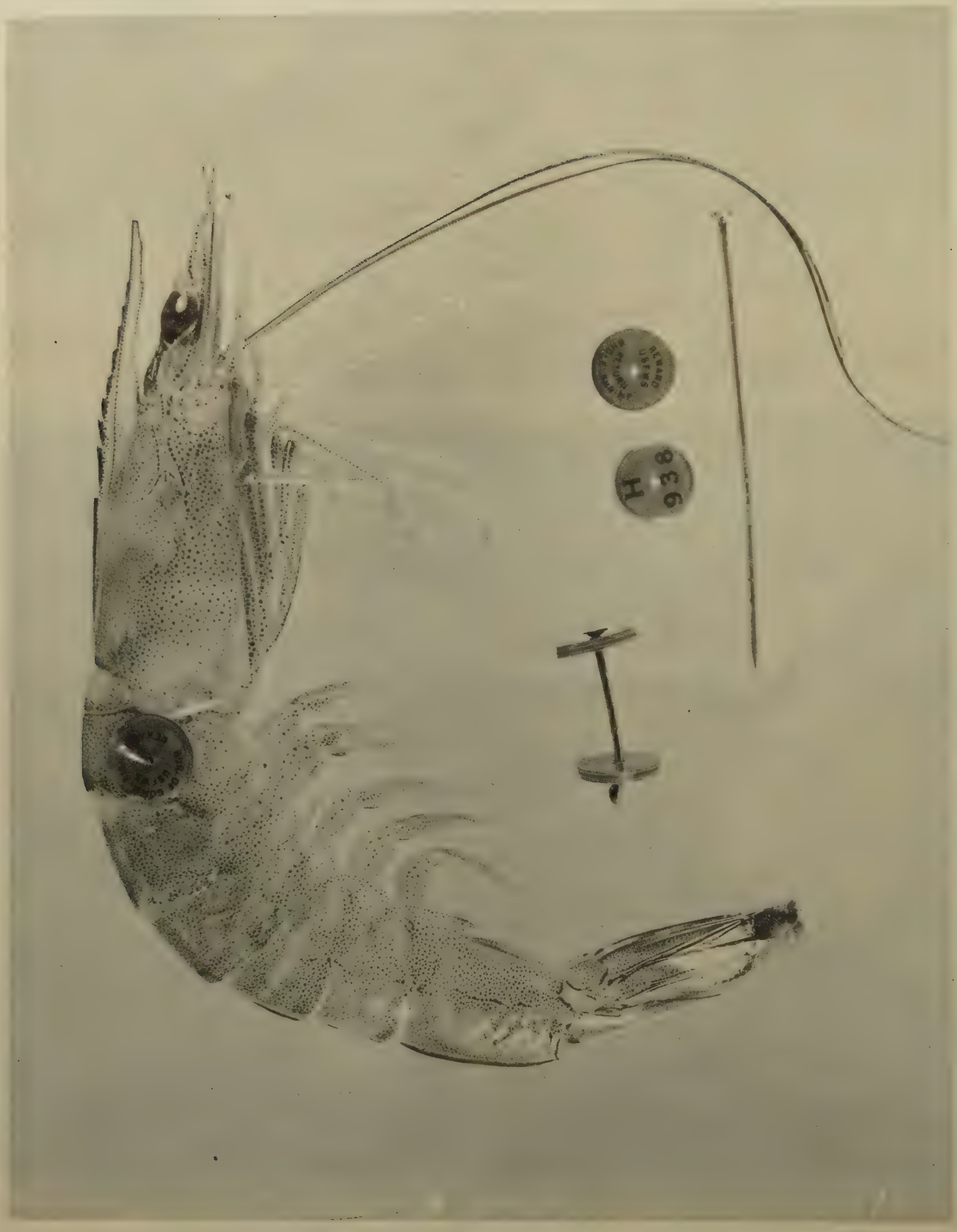


Fig. 8.13 Shrimp marked with the Petersen disc tag. (from Neal 1969)

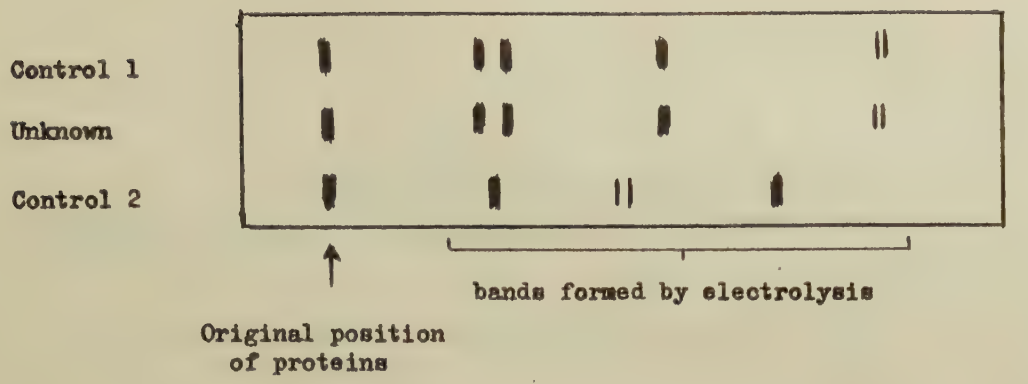


Fig. 8.14 Slide showing stained bands after electrolysis of proteins through an agar gel: unknown belongs to same group as Control 1

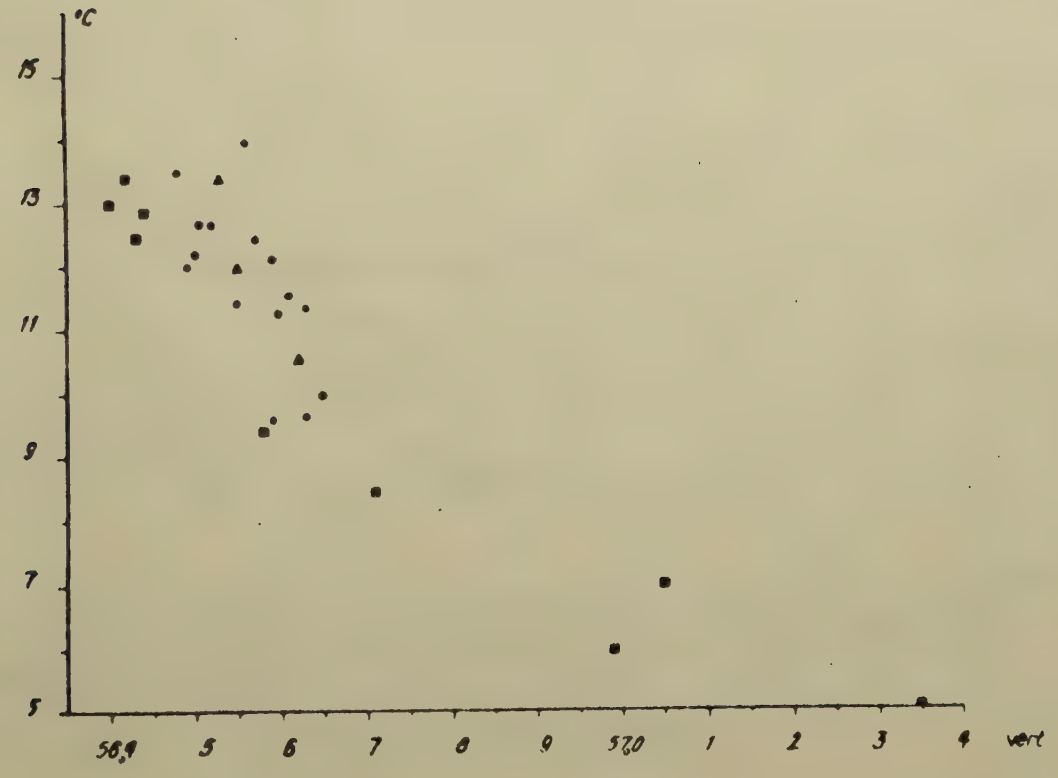


Fig. 8.15 Relationship between mean number of vertebrae and temperature on various spawning grounds (see text)
■ = data from Le Gall, Runnström and Wood.
▲ = total 1952, 1953, 1954.
• = year-class means

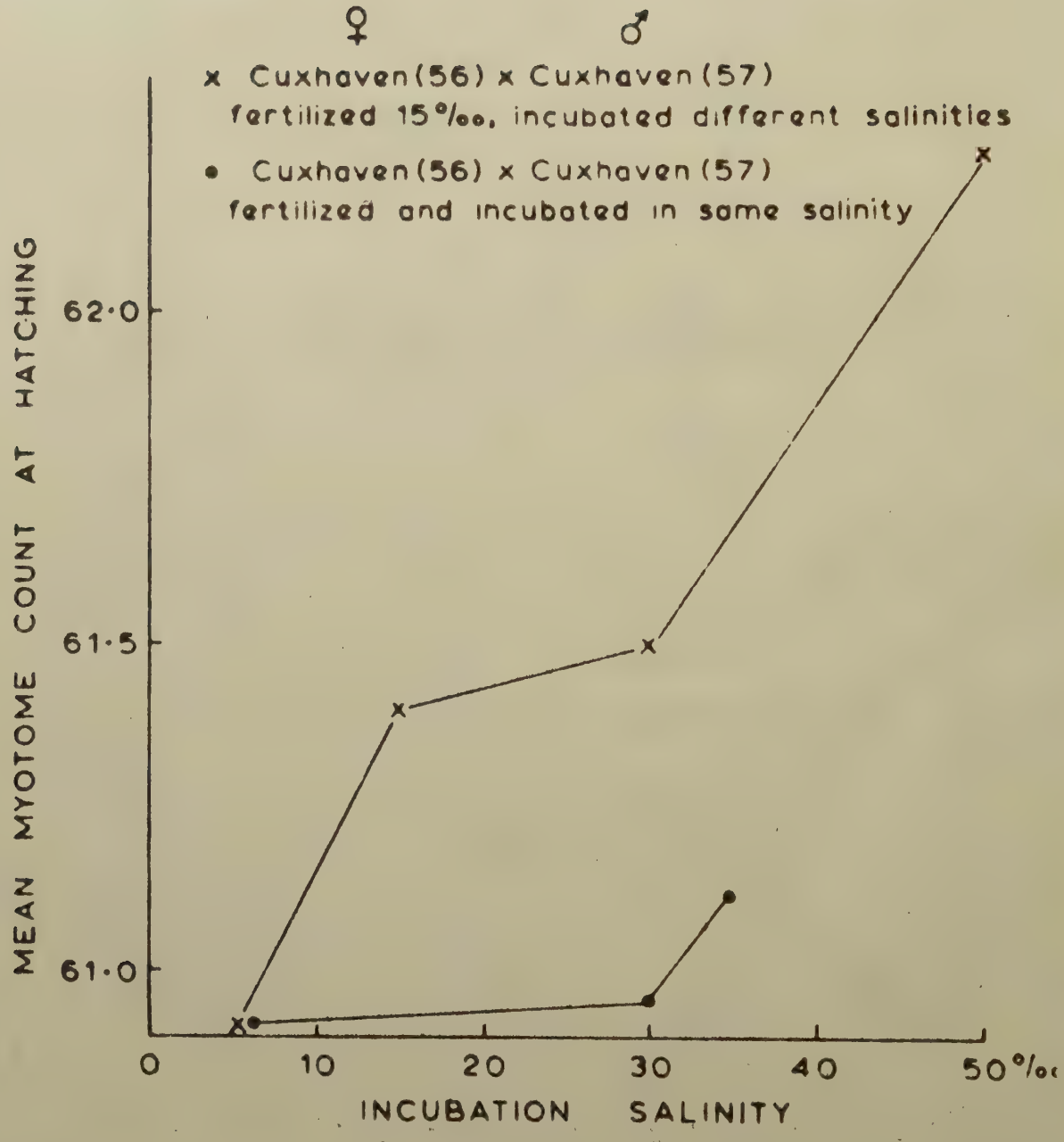


Fig. 8.16 The effect of incubation salinity on mean myotome count. (Hempel and Blaxter (1967))

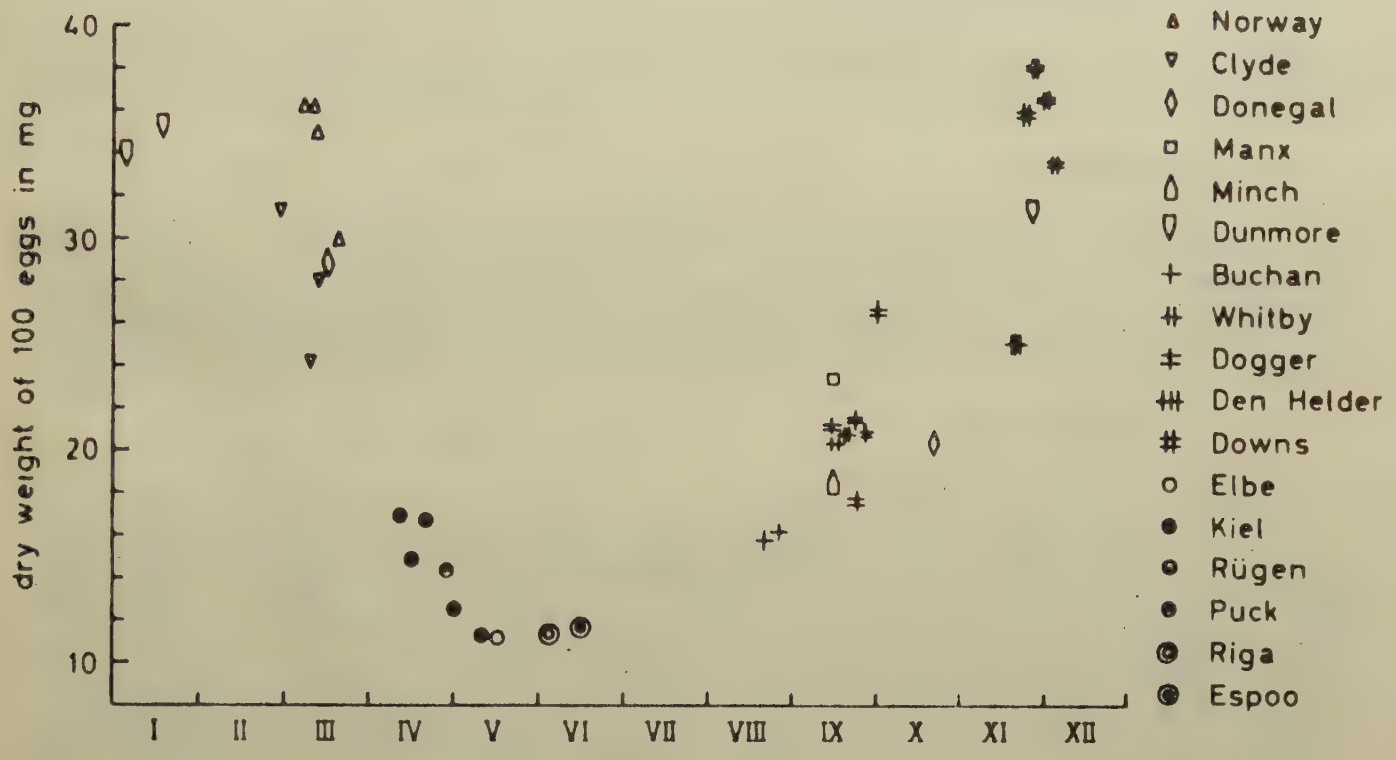


Fig. 8.17 Relation between individual egg weight of various stocks of North-East Atlantic herring and month in which fish of each stock spawn.

9. THE EFFECT OF FISHING ON FISH

9.1 Introduction

The practical fisheries biologist collects data to answer two main questions: 'how much fish is there in the area that it is intended to fish?' and 'what is the maximum amount which can be caught annually without affecting the ability of the stock to produce that yield?'. Incidentally he may satisfy his scientific curiosity about the biology of the fish he studies or the environment in which they live, but he should never lose sight of his main objective, to answer these two questions.

So far, the sections of this manual have been concerned with what data to collect and the best ways of collecting them. In this section the uses to which the data are put will be described.

9.2 How Much Fish?

There are two ways of approaching this problem; one is to determine the total quantity of fish present in absolute terms, that is, the question is answered in terms of either total weight (3 million tons) or total numbers (60 million fish); the other is to answer it in relative terms, that is, the question is answered in terms of tons of fish caught in an hour's fishing. Reviews of methods of resource appraisal are given by Alverson (1971) and Mackett (1973).

9.2.1 Absolute methods

9.2.1.1 Release and recapture

This method is based on the fact that if T individuals are marked or tagged in a total population of N individuals, the probability that an individual will be marked in a random sample from the population is T/N. If n specimens are caught and m of these are found to be marked then the number of fish in the population is $N = nT/m$. Putting this in practical terms, assume that 3,000 fish had been tagged during an experiment ($T = 3,000$) and that in the 12 months following their release 3 million fish of this species had been landed from the stock into which these had been tagged ($n = 3 \times 10^6$). This number would be calculated from the market sampling programme (sections 2 and 3); from theselandings the fishermen had returned 750 tagged fish ($= m$). Then an estimate of the number of fish of marketable size in the stock (N) would be $nT/m = 3,000,000 \times 3,000/750 = 12$ million fish.

Several assumptions are made in this calculation which are:

(a) tagged and untagged fish are evenly mixed (which would be improbable from a normal tagging experiment);
(b) the mortality rates or the emigration rates or both of tagged and untagged fish are the same;
(c) tagged and untagged fish are equally liable to capture by the gear;
(d) there is no mortality caused by tagging, no tag shedding and that all tagged fish are returned.

Even if all the conditions are fulfilled the estimate of N obtained is biased. A better method involves multiple captures and recaptures, giving the following formula (from Cormack, 1968):

$$\hat{M}i = Z_i = (S_i/r_i) + Mi$$

in which $\hat{M}i$ = estimated number of individuals marked at time t_i

Z_i = number of fish marked before t_i not caught at t_i but recaptured on later occasions

S_i = number of fish marked at time t_i

r_i = number of fish, S_i, recaptured on later occasions

M_i = number of marked fish at start of time t_i

then $\hat{N} = (n_i/m_i).\ \hat{M}_i$

in which $\hat{N}_i$ = number of fish in population at time t_i

n_i = number of fish caught at time t_i

The method is still dependent upon assumptions a-b being valid. Marking and recapture methods have their potentially most useful application in small, enclosed bodies of water such as ponds and small lakes, but even in small pools it may be very difficult to obtain reliable estimates of population size (see Holden, 1963).

9.2.1.2 Swept area and swept volume

Some fishing gears such as trawls and seines sweep a volume of water. This volume can be calculated approximately from the dimensions of the gear. If it is assumed that the gear catches all the fish in its path a minimum estimate of the number of fish can be determined if the volume of sea the stock inhabits is known. This method is a minimum estimate because it assumes that all the fish in the path of the gear are caught, which is unlikely. For pelagic trawls avoidance can be either so great or so effectively eliminated by aimed fishing that the method has its main application to gears hauled along the seabed. The calculations are made in terms of area. Say 1,000 trawl hauls were made in a random manner over 100,000 square miles of seabed inhabitated by a stock. Assume that each trawl haul swept 0.5 square miles of seabed and that the average catch was 60 fish. In sweeping 500 square miles of seabed (1,000 hauls x 0.5 square miles) 60,000 fish were caught (60 fish x 1,000 hauls). So in 100,000 square miles the estimated number of fish is 60,000 x 100,000/ 500 = 12 x 10^6 fish. This method can be very useful in giving a first estimate of the quantity of fish which is present.

9.2.1.3 Egg and larval surveys

The use of egg and larval surveys to estimate stock numbers has already been described in section 7.3.3. The method can be very useful for fish with pelagic eggs, if those eggs can be readily identified either to species or species groups.

9.2.1.4 Acoustic techniques

Simple echo-sounders will give some idea of the abundance of fish but echo-sounders used with integrators give very good estimates of fish abundance, particularly of pelagic species. The methods are described in detail by Forbes and Nakken (1972).

Simply, echo-sounders work by sending a sound wave into the water. If this sound wave hits an object which will reflect it part of this sound wave is reflected back, the amount depending upon the type of object and its depth. When it is received back by the transducer of the echo-sounder it is converted into an electrical current which is then used to

operate a display. Integrators work by adding the voltages of the returned electrical current and displaying the response on a calibrated chart. They also make allowance for the object's depth so that a sound wave reflected from a fish at 50 m will give the same amount of record as one at 10 m. Fish of different species and size give different responses but once the equipment has been calibrated for the species being surveyed the absolute quantity of fish can be determined from the integrated record. Regular fishing has to take place during the survey to determine what species are responsible for the record, unless it is known that only one species inhabits the area or unless a multi-species assessment is acceptable.

9.2.1.5 Virtual population analysis

This is a technique which can be used if most of the stock is caught and the age structure of the catch is fairly accurately known. In this method the results obtained from market sampling and age determination programmes are used.

By making two assumptions, one about the natural mortality rate and the other about the fishing mortality rate on the oldest age-group in each year-class it is possible to calculate by a reiterative process the numbers of fish in each age-group in the stock. The method works by considering each year-class separately and calculating the size of that year-class at the beginning of each year and the fishing mortality acting on it throughout that year. The estimates of these two parameters get increasingly more accurate as the calculation proceeds from the oldest to the youngest fish in a year-class. The accuracy of the first two or three estimates depends upon the correctness of the initial value of the fishing mortality rate. Full details of this method are given by Fry (1957), Gulland (1965) and Pope (1972).

9.2.2 Relative methods

Relative methods are based on some form of catch per-unit-effort index, calculated from either commercial or research vessel information. They are relative because they indicate only what is happening to the abundance of the stock and not its actual total size; abundance is usually measured as catch per-unit-effort.

9.2.2.1 Commercial indices of catch per-unit-effort

The calculation of commercial indices of catch per-unit-effort has been given in section 2 in which methods of collecting catch and fishing effort data were described and the importance stressed of collecting effort data which give a meaningful index of fish. The last-named point is most important, particularly as the efficiency of vessels changes or as completely new types of fishing are introduced.

Catch per-unit-effort is used in many ways. Firstly it can be used to describe changes in the abundance of the stock from year to year. Used with total catch data it can be used to describe a simple model from which the long-term sustainable yield from a stock can be calculated (Gulland, 1969). It is also used in calculating total mortality rates from the numbers in successive age-groups of a year-class landed in two subsequent years. For example, 1,000 fish aged 5 years might be landed one year and 500 fish aged 6 years the next year. As these are total catch figures they give no indication of the abundance of this year-class in the two years. However, if fishing effort in the second year was twice that in the first the relative abundance was 1,000 : 250 (1,000/1:500/2). The survival from one year to the next of this particular year-class was 0.25.

9.2.2.2 Research vessel indices of catch per-unit-effort

One of the difficulties of commercial indices of abundance has already been mentioned which is that the efficiency of the boats changes from year to year. Another is that there is no control over where the fleet fishes. In a fishery for two or more species the fleet will concentrate on that species which gives it the best financial returns and this is likely to

alter both seasonally and annually. To some extent the problem can be overcome by using indices calculated for those periods during which both the stock and the fishery is concentrated; for example, during the spawning season.

Research vessel surveys overcome these problems to a large extent and also can be planned so that the standard deviation of the answers can be calculated. A commercial index may show that the catch per-unit-effort has fallen from 5 to 4 tons per hour's fishing but it is not possible to say from this that the abundance has fallen by 20 percent. However, a research vessel survey might show that it has gone down from $5^{\pm}$ 0.2 tons to $4^{\pm}$ 0.25 tons/per hour's fishing. The 95 percent confidence limits are approximately twice the standard deviation (section 2.3.3) so it is 95 percent certain that the catch per-unit-effort has fallen from between 5.4 and 4.6 tons to between 4.5 tons and 3.5 tons per hour's fishing. It is 95 percent certain that there has been a real fall in abundance.

To obtain results with a known standard deviation it is necessary to base the surveys on the use of statistical techniques. Jones and Pope (1973) describe a survey of Faroe Bank in which they divided the area as shown in Fig. 9.1. This is an example of stratified sampling (section 2.4). In each stratum they laid a grid of potential stations and then selected two at random (see section 2 ... for the use of random numbers). They also stratified fishing by time intervals so that they could consider the effects of diurnal variations in abundance. (Methods of fishery resource survey and appraisal are given by Alverson (1971) and Mackett (1973)).

9.2.3 Effects of gear upon sampling

The first that are caught are unlikely to be a true sample of the population and the landings of a commercial fishing vessel even less likely to be because a certain amount of sorting and discarding will have taken place at sea. This can be checked upon during interviews to obtain catch, fishing effort and fishing ground information (section 2.10). More importantly the catch will depend upon the selectivity of the gear and how it is rigged.

9.2.3.1 Mesh selection

Most gears do not catch a random sample of all the fish present; they 'select' either big fish or small fish.

One of the best studied cases of selectivity is that of trawl cod-ends. For a given mesh size in the cod-end all the small fish will pass through and all the large fish will be retained but somewhere in the middle of this range there will be a length range in which some of the fish of a certain size are caught, because they are too fat to pass through the meshes but others of the same size get through because they are sufficiently thin. If the proportion retained at each length is plotted against length a sigmoid curve results (Fig. 9.2a). The important feature of this curve is the point length at which half the fish are retained and half escape, the 50 percent selection length. This, divided by the mean mesh size of the cod-end, gives the selection factor. (The mesh size is measured with a special spring-loaded gauge). Further details of trawl selectivity and methods of studying it are given by Pope (1966). Holden (1973) gives a complete bibliography of references.

Once the selectivity curve is known correction can be made for the fish in the length range retained by the cod-end; that is, if 50 fish were retained in the length range for which selectivity was 0.25, 200 fish actually entered the cod-end (50/0.25 = 200).

For gill nets the selectivity increases to a maximum, as for cod-ends, but then declines to zero as the fish become too big to be retained by the gear (Fig. 9.2b). Methods of studying gill net selectivity and for correcting catch-data obtained with gill nets are given by Holt (1963).

Hook selectivity also occurs; in general hooks take proportionately more large than small fish. This has not been studied in detail and, as yet, there is no standard method of correcting catch data for it.

9.2.3.2 Gear selection

Besides mesh selection gear selection for both species and size is often found. That different gears are not equally effective in catching different species might be expected. When trawlers have fished on the same grounds as Danish seiners, the species' composition of the catches has been very different. From experimental results Margetts (1949) estimated that over a standard 24-hour period a Danish seiner caught 2.8 times as many plaice as a trawler; the trawlers caught relatively far more soles, anglers' fish, turbot, and brill than did the seiner. It was also estimated that the area of seabed fished by the seiner, taken as the area swept by warps and net, was about 3 times that covered by the trawl. Thus, the efficiencies of the two gears, as judged by their abilities to catch so many fish per unit of ground, were approximately the same on plaice but the trawl was more efficient for catching species such as sole.

Minor differences between gear may also cause differences in efficiency. The majority of cod-end mesh selection experiments have shown that larger meshes catch more fish of lengths beyond the 100 percent retention point. Table 9.1 gives the ratio of the total catches of plaice obtained for equal fishing times by two trawls with different mesh size in the cod-end. In theory the ratios should not exceed 1.0. The discrepancy may result from different water flows through the cod-ends.

Table 9.1. Mesh selection of plaice. Ratios of catches of large to small meshed cod-ends (140.6 mm: 44.5 mm)

Length cm	Ratio of catch in No. per hour
19.5	.01
20.5	.03
21.5	.03
22.5	.04
23.5	.06
24.5	.05
25.5	.11
26.5	.12
27.5	.15
28.5	.32
29.5	.42
30.5	.96
31.5	.78
32.5	.86
33.5	.82
34.5	1.13
35.5	1.09
36.5	1.13
37.5	1.20
38.5	.85
39.5	1.17
40.5	2.00
41.5	.50
42.5	2.33
43.5	1.13
44.5	.50
45.5	.80
46.5	4.00
47.5	1.00
48.5	1.50

(from Beverton and Holt 1957)

Catch data obtained during a comparison between the two British research vessels SIR LANCELOT and EXPLORER showed that SIR LANCELOT caught fewer small haddock, but more large haddock than did EXPLORER (EXPLORER caught 1,262 haddock of length 31-44 cm, 61 haddock of length 45-56 cm compared with 406 and 88 haddock in the same groups in SIR LANCELOT's catches). The trawls were fitted with cod-ends of approximately the same mesh size but they had different numbers of floats and different bridles. Later, by means of underwater photography of the trawls, the fishing shape of both of them was determined. EXPLORER's net had a wide-spread but a small vertical gape and SIR LANCELOT's had a relatively small-spread but a much higher vertical gape. This suggests that SIR LANCELOT's trawl caught more big haddock because they were swimming rather higher off the bottom than the smaller ones.

All sections of a gill net are not equally as efficient at catching fish as shown by the catches of salmon in relation to their distance from the leadline of the net (Table 9.2). This point was also mentioned in Appendix 2; Sampling an African lake fishery.

Table 9.2. Relationship between number of salmon caught per 1,000 gill nets in the Baltic and the distance between upper rim of net and sea surface

Distance cm	Number of salmon
5-10	158
15-20	136
30	68
40	50

(from Christensen 1970)

Catchability of a species may change as behaviour alters with age. Sprat (Sprattus sprattus (L.)) in the Wash, southern North Sea, form two distinct layers of vertical distribution, an upper layer of two-year-olds and a lower one of three-year-olds. Commercially the sprats are caught by mid-water trawls but as the fishermen do not like to tow them too deeply in this area of sandbanks, their catches consist mainly of two-year-olds. In this case the catch per hour's trawling is a quite unreliable measure of abundance of three-year-olds (Cushing, 1968).

Catchability can also change from one season to another. Adult Sardinella aurita are caught pelagically in inshore waters during the upwelling season only. The rest of the year they are probably below the thermocline in deeper waters. The best index of abundance in this case would be the catch per-unit-effort at the height of the fishing season.

For Sardinella, it is evident that an index of abundance from the main season in one year cannot be compared with an index from the off-season in another year. It is a general rule that this should not be done; indices from the same season or means for the whole year are preferable.

The effect of diurnal changes has already been noted in section 9.2.2.2.

9.2.4 Summary

This sub-section has dealt with the question of how many fish are present. Not only have methods of determining this been described but also the biases inherent in the sampling methods used. The results from these methods also give the answers to what species are present and to when and where they are available for capture. In a developing fishery the determination of the available species' composition will decide not only the best methods of capture but also the outlets for the product. When the fish are available is also of vital

importance; a single survey conducted during a period when the fish were maximally available would lead to a totally false conclusion about the viability of a potential fishery. Where the fish are available also determines choice of gear and fishing units. This is the period of 'Prospection'; now we turn to 'Stock Assessment' (Fig. 1.1).

9.3 Population Dynamics

Population dynamics is the study of the effect of fishing upon fish. The vast majority of fisheries take place on wild stocks over whose reproduction, growth and natural mortality man has no control whatsoever. The only way in which he can predictably affect these stocks is by the pattern of fishing which he adopts, although he may also affect the other three factors in an unpredictable manner.

9.3.1 Construction of a model

When a man wants to predict the effects of his interference with a system, he must construct a mathematical model of it. The number of factors influencing such a system is very high and in the beginning it is necessary to simplify the model by leaving out many factors and concentrate on those of most interest. Even if the model is very simple and even if it is very soon found not to describe the system very well, it can be quite useful to the scientist by helping him to understand the dynamics of the system better. Only by constructing and using a model will he be able to ask meaningful questions and to collect the data of most use to him at the moment. (see also section 2).

Russell (1931) was one of the first to express the factors which affect the size of a fish stock by his formula:

$$S_2 = S_1 = (A + G) - (C + M)$$

in which S_1 = the size of the stock at the beginning of the year

S_2 = the size of the stock at the end of the year

A = recruitment

G = growth

C = catch

M = deaths due to natural causes.

If the stock is to be in equilibrium ($S_2 = S_1$), then $A + G = C + M$ or $C = A + G - M$. This is a very simple way of considering the factors which govern stock size but the formula cannot be used as it stands and in the past forty years fishery biologists have described various models to express the terms in the equation by means of parameters which can be determined from observations. How to obtain these observations is the subject of this manual. Additionally, he has set out to determine the effect of changes in that parameter which is potentially within man's power to control, namely the amount of fishing activity. In the simple case it is assumed that the number of recruits, the growth rate of an individual fish and the chance of survival of an individual are unaffected by the density of the stock; in other words, they are the same whether the catch is zero or very large.

From determinations of age, length and weight, mean lengths and weights at age can be found: these are all end products of the sampling systems described in sections, 2, 3 and 4. From these a model can be constructed to express either length or weight as a function of age; the weight function is curve A in Fig. 9.3. Similarly, from age determinations and from catch in numbers per-unit-effort the relative density can be found for a year-class

at different occasions during its life and a model constructed to express the numbers of the species as a function of time. This function is shown as Curve B in Fig. 9.2. The product of the number present at a certain age and the mean weight at that age gives the biomass at that moment (Curve C, Fig. 9.3). The Curve C has a maximum and to get the maximum catch the year-class should be fished out at that age. In practice this is impossible as it requires an infinitely great effort during a short period and no fishing for the rest of the year. Also, year-classes are mixed and it is impossible to fish them singly. This simple model is insufficient; for economic reasons the effort must be distributed throughout the year and thus start taking its toll before the maximum biomass is reached and continue after the decline has begun. The fishery is also carried out on more than one year-class at a time and the model must be extended to take this into account.

Graham (1939) described Curve B (Fig. 9.3) in a very simple way, by taking an initial number of fish say 1,000, and calculating the survivors after a year for a given total mortality rate, say 50 percent a year. At the end of the first year there would be 500 survivors, at the end of the second 250, at the end of the third 125 and so on. The decline is termed 'exponential' and can be more easily calculated using exponential functions, those based on power of the constant e. (The determination and use of this constant is described in most books on calculus). However, this is a tedious method of calculating the effect of fishing and eventually yield equations were derived by Ricker (1948) and by Beverton and Holt (1957) which enabled mortality rates and growth in weight to be combined in a single equation (see also Gulland, 1969).

9.3.2 Use of the models and the results

These yield equations are simply means of integrating growth, fishing and natural mortality rates to give assessments of yield for each of the factors with the other two held constant. As the models on which they are based assume constant recruitment the results given by them are in terms of yield per recruit (Y/R). A simple outline of this model is given in Fig. 9.4a. Such models are called deterministic; every factor is fixed for the whole cycle of the fishery and none of them are altered by changes in the other factors. These models have been used in fisheries for the last 20 years and have been very useful in stock assessment. They have enabled the fisheries' scientist to determine at what point the fishery is in relation to long-term sustainable yield and fishing effort (Fig. 1.1, points C, D, E or any other point), and to describe the effects of changing this level of fishing effort (or more accurately fishing mortality rate). Also, they have enabled the effects of allowing the age at which the fish are first caught (age of recruitment) to be calculated (Fig. 9.4a, b). The disadvantage of these models is that they are only qualitatively predictive because all the answers are in terms of yield per recruit. Quantitative prediction depends upon knowing either the number of recruits or using models which incorporate the age structure of the stock in numbers.

Within the last five years virtual population analyses (section 9.2.1.5) have been extensively used to give us this information and used with estimates of recruitment obtained from surveys of larval and pre-recruit fish have enabled fisheries' biologists to predict quantitatively. Within ICNAF and to some extent within NEAFC (North-East Atlantic Fisheries Commission) fishing is controlled by quotas which have been calculated in this way. Manipulation of the data has also been made easier by the use of computers.

9.3.3 The future development of models

Models which allow variation of the parameters are called 'stochastic', as compared with those which are 'deterministic'. Such models are complex and difficult to study without the use of computers but they enable the possible effects of stock size on growth rates, natural mortality rates and recruitment to be studied (Fig. 9.4d) but nothing is known about variations in natural mortality rates with stock size but growth rates of many species are known to be density-dependent; however, most attention has been paid to the question of the dependence of recruitment on stock size.

At present it is a matter of dispute whether fishing can or cannot affect the number of recruits to the fishable stock of a teleost fish species. For a long time it was assumed that within the range of abundances in which a fishery would be economically-viable the number of spawners would always be sufficient to produce enough eggs to replace the losses due to fishing and natural mortality. Recently this assumption has been questioned. It seems highly probable that the fisheries for certain stocks such as the Hokkaido-Sakkalin herring, the Norwegian herring, the Japanese sardine and the Californian sardine collapsed because the number of adult females was no longer enough to maintain the stock at a level at which fishery was profitable (Cushing, 1971). To incorporate effects of fishing upon recruitment into the models knowledge of both fecundity (section 5) and the life history of the larval fish (section 7) can be required. Other uses to which the basic data can be put are studies of the interaction between fisheries and of the interaction between species in the same fishery. The latter has been mentioned in section 6.

9.3.4 Monitoring the stocks

The final task of the fisheries' scientist is to help maintain the stocks at whatever level has been decided upon (B, C, D or E or in any other level in Fig. 1.1). Usually the level chosen is 'D' or at some point between 'D' and 'E', (Fig. 1.1). To do this he must monitor it (routinely collect all the data described in sections 2, 3 and 4 and conduct pre-recruit surveys) so that he can predict what catches can be taken from the stock without affecting its ability to continue giving catches at this level, depending upon recruitment. He must also be able to give advice on any problems that may arise either with the introduction of new methods of fishing or from natural changes in the availability or abundance of the stocks.

9.4 International Coordination and Cooperation

The riches of the sea outside limits are free for everybody to fish and the exploitation of the living resources of the sea has become increasingly important to more and more countries. The problems are not so intensive in freshwater fisheries but they exist there also.

To protect these resources against overexploitation internation coordination is necessary. There is little sense in one nation regulating its catch in an international fishery if no other nation does the same because the nation that regulates will lose while the others benefit. Only if every nation is to gain equally, usually after some initial losses which must also be shared equally, will nations agree to cooperate.

As a fish stock is often exploited by several fleets from different countries it is necessary that all countries collect catch statistics and preferably in the same way. This was emphasized in sections 2, 3 and 4. For other studies it is not essential to collect data in a standard way, although by doing so it simplifies the exchange of information. Coordination of work is essential if more than one nation fishes a stock, if only to determine the total catch which is being taken from that stock. In many cases nations fish different parts of the stock so that catch per-unit-effort of one fleet may not be representative of the abundance of the whole stock. For example, the British trawler fleet fishes in the Barents Sea on the immature part of the Arcto-Norwegian cod stock; these fish are mainly 3 to 7 years old. The Norwegians fish this stock at the Lofoten Islands where it spawns and their catch consists of fish older than 7 years. Thus there is a sequence of high indices of catch per-unit-effort as large year-classes pass through the fishery; initially it is high in the British fishery and then high in the Norwegian fishery. For virtual population analyses it is essential to have complete age compositions for the catch which means that those nations which catch most of the fish must provide data before the analysis can be attempted. Coordination of work can also make some studies feasible by cutting the cost to individual states; 0-group surveys of marine teleosts are largely conducted on an international basis.

The task of combining the result of numerous research programmes and of channelling them to the governments managing the fisheries' policy in the different countries is to a great extent undertaken by a number of international organizations, mainly through Regional Commissions consisting of the countries exploiting the area. An historical account of the development of collaboration in fisheries research with particular reference to the North Atlantic Region is given by Lucas (1963) and a review of international organizations has been published by the U.S. National Oceanographic Data Center, 1969 as "Annotated Acronyms and Abbreviations of Marine Science Related International Organizations".

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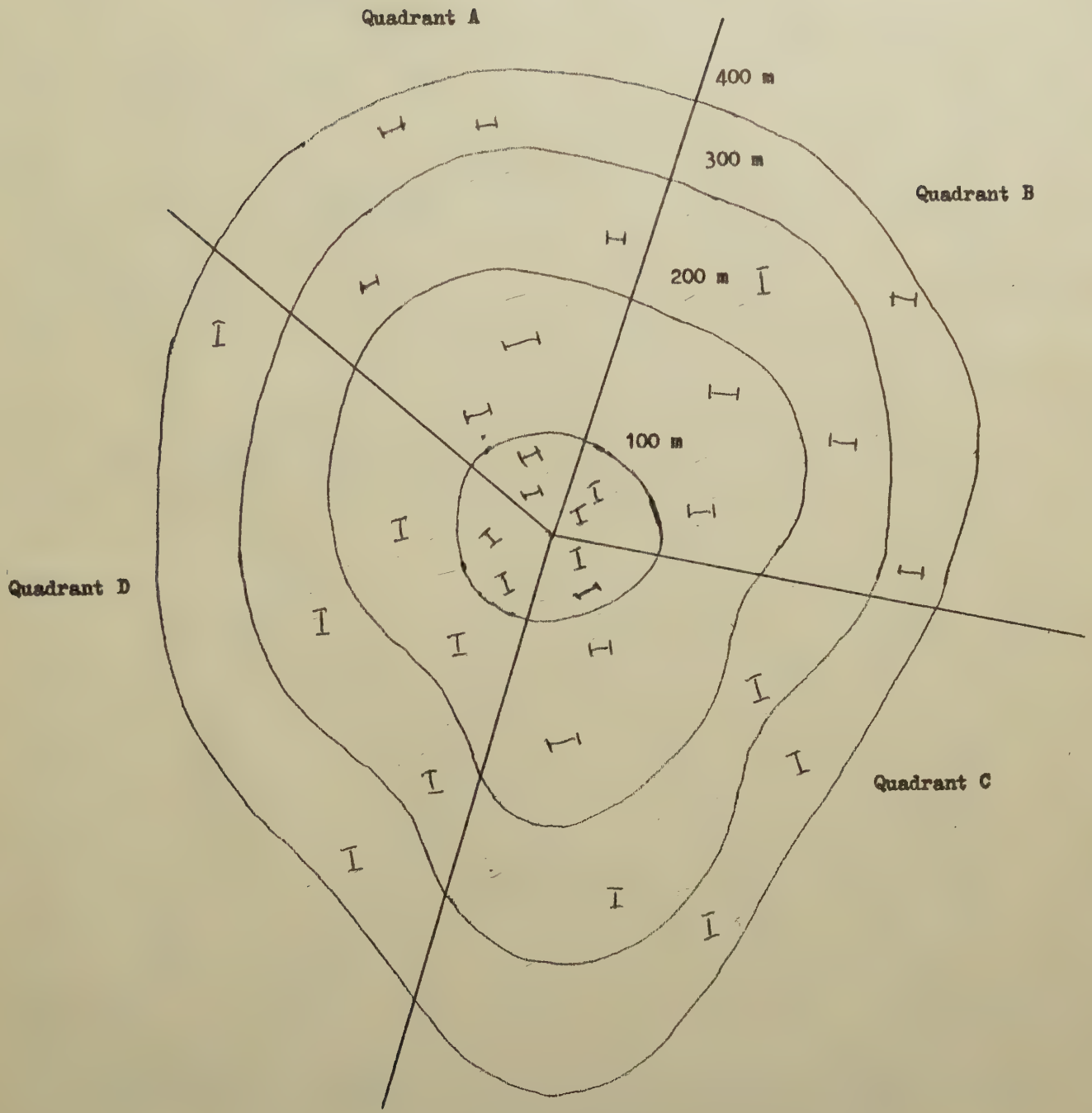
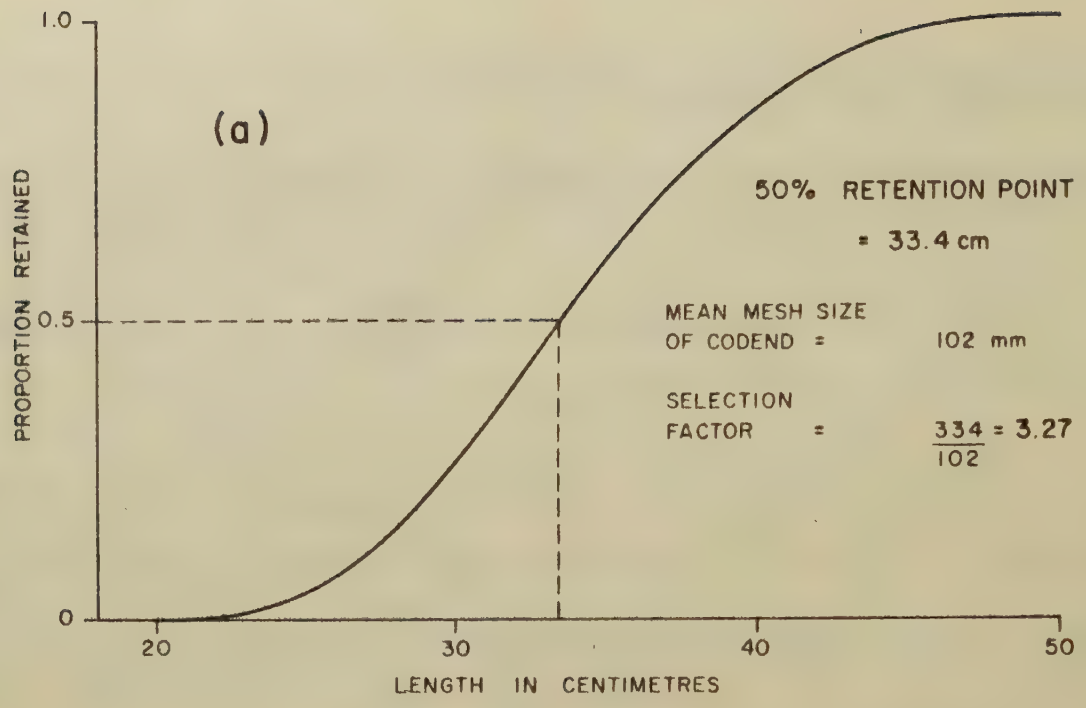


Fig. 9.1. Stratification of Faroe bank by quadrants A–D, each of equal, and by four, depth zones, less than 100 m, 101–200 m, 201–300 m and 301–400 m. Trawl hauls, chosen from a potential station grid by random numbers shown thus - I. Modified from Jones and Pope (1974)



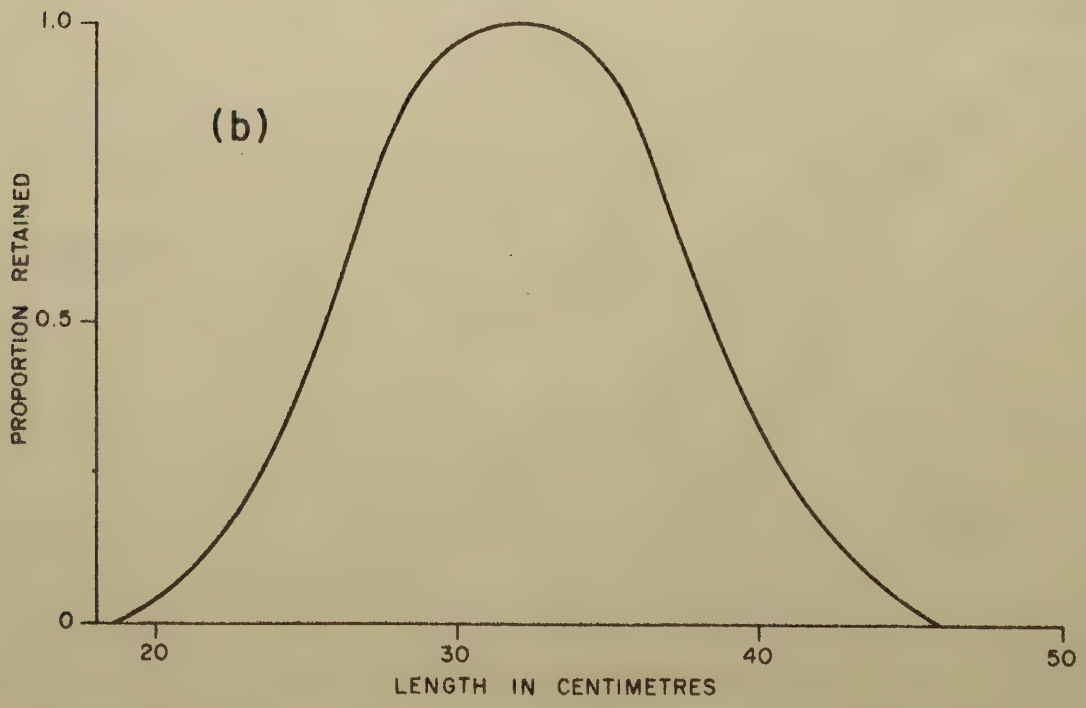


Fig. 9.2 Selection curve of cod-end (a) and of gill-net (b)

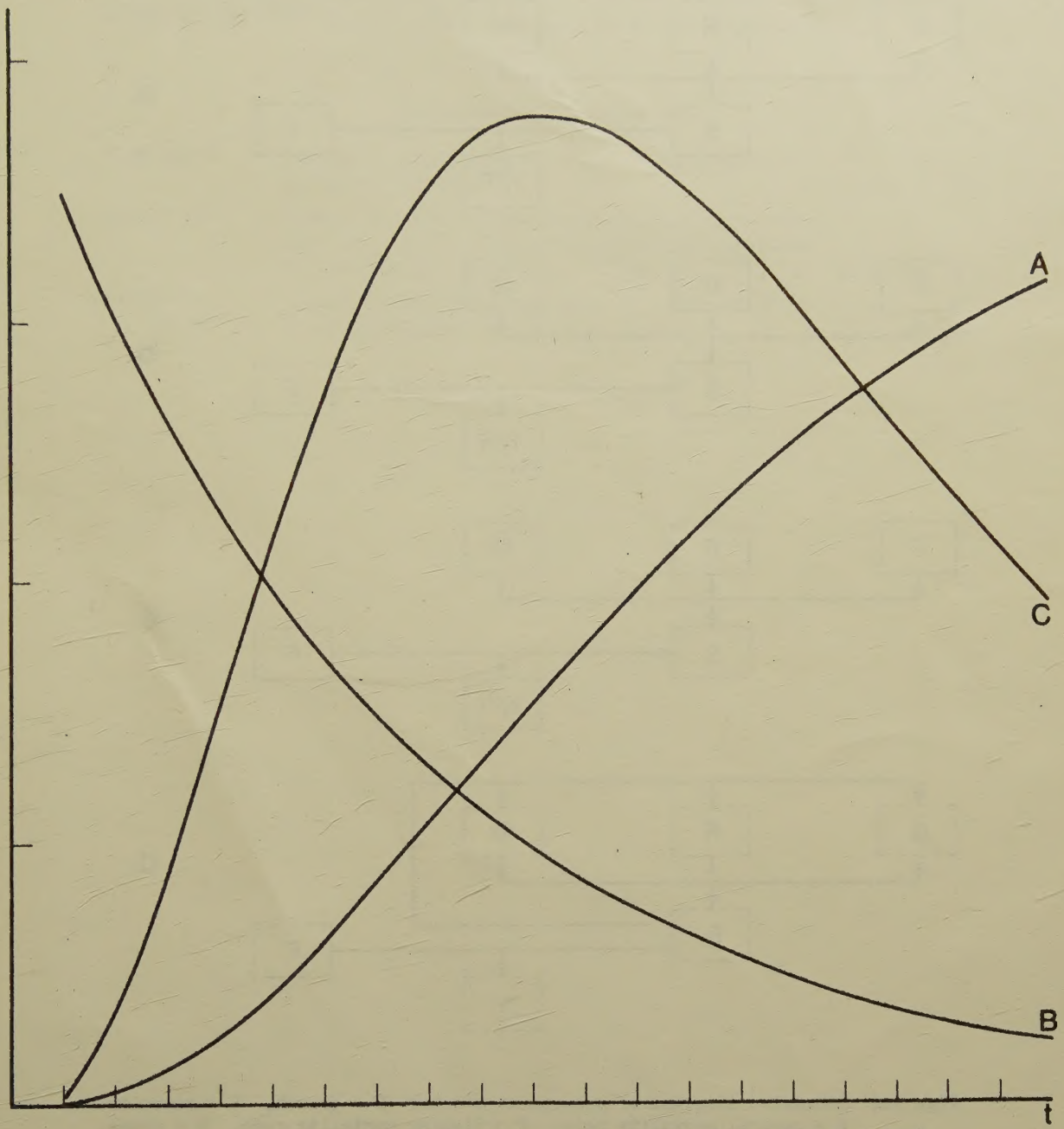


Fig. 9.3 Curves showing (A) increase in weight of an individual fish (B) decline in number of a year-class and (C) total biomass of a year-class, the product of (A) x (B), with time (t)

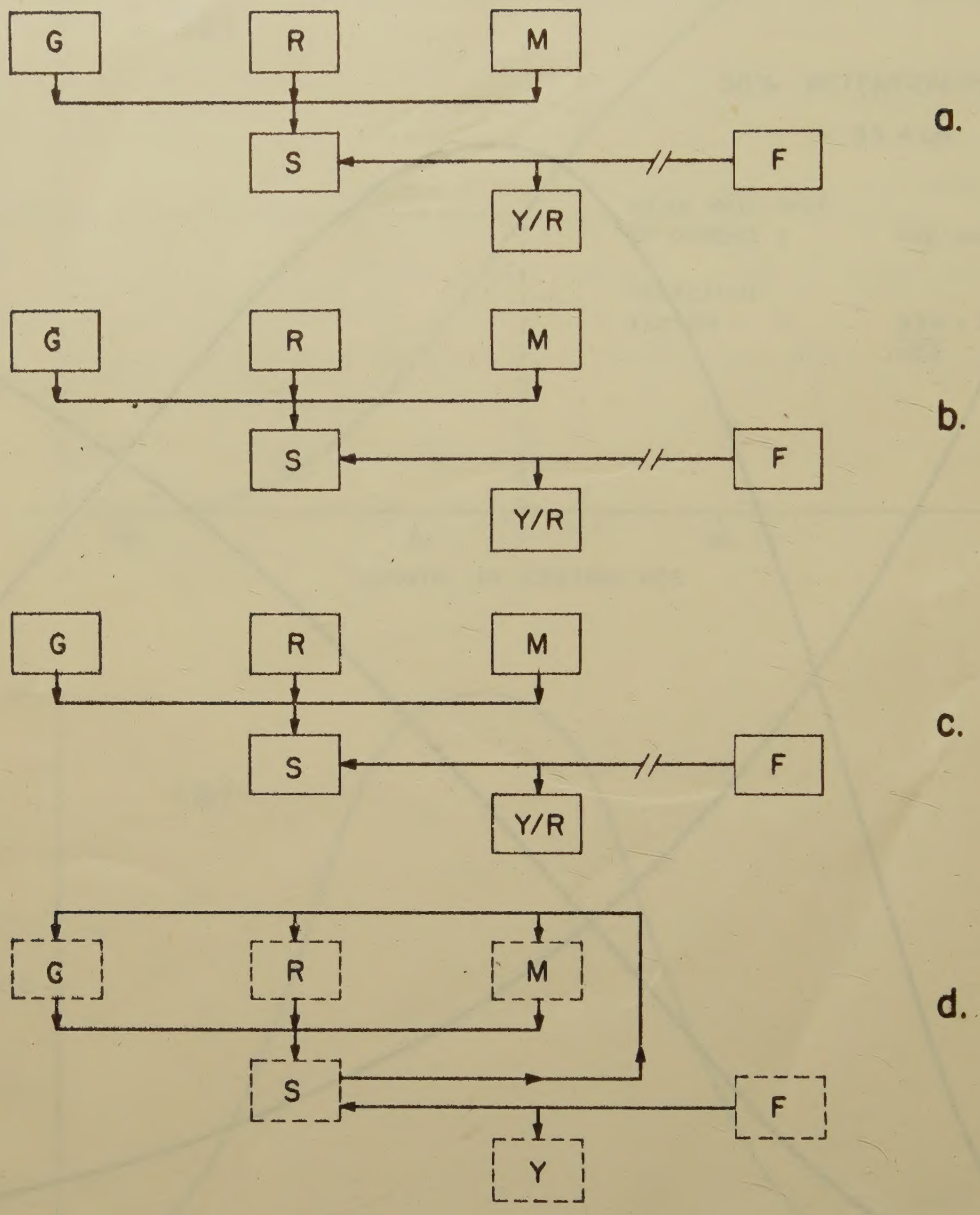


Fig. 9.4 Schematic diagrams of assessment models: G = growth, R = recruitment, M = natural mortality rate, F = fishing mortality rate, S = stock, Y = yield, Y/R = yield per recruit; a, b, c are based on a deterministic model in which F has no effect on G, R or M. a) initial state, b) mesh size increased (indicated by //) and Y/R increases, c) fishing mortality rate increases and Y/R decreases, d) represents 'stochastic' model in which age of S affects G, R and M as well as Y

FAO FISHERIES TECHNICAL PAPER (MFS)

Documents in this group are provisional editions of volumes or sections of FAO MANUALS IN FISHERIES SCIENCE, usually in the language of the original draft. They are given a limited distribution for comment by collaborators in the project, and for use of FAO headquarters and field staff and at training centres, courses and seminars. Revised versions are subsequently published by FAO in the official languages of the Organization.

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